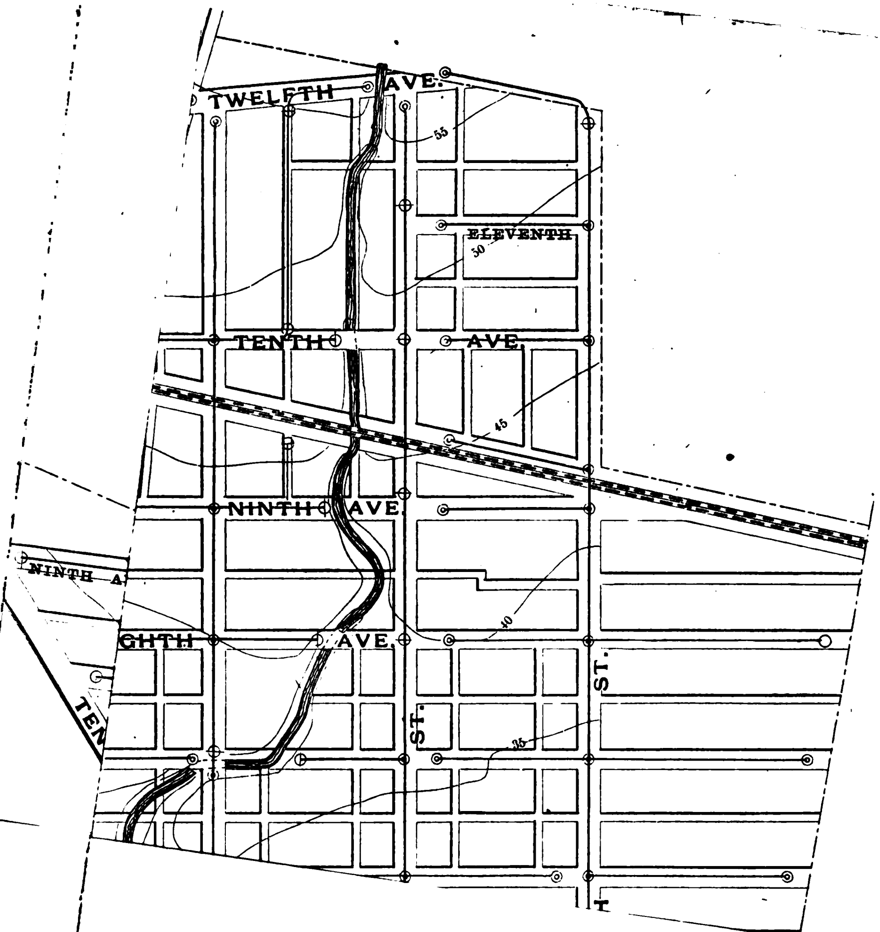

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THE

SEPARATE SYSTEM

OF SEWERAGE:

ITS THEORY AND CONSTRUCTION.

BY

CADY STALEY,

PRESIDENT OF CASE SCHOOL OF APPLIED SCIENCE, CLEVELAND, O.,

AND

GEO. S. PIERSON, C. E.,

MEMBER OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS.

SECOND EDITION,

REVISED AND ENLARGED,

WITH A CHAPTER ON SEWAGE DISPOSAL.

NEW YORK:
D. VAN NOSTRAND CO.
23 MURRAY AND 27 WARREN STREETS.
1891.

FROM THE PRESS OF
IHLING BROS. & EVERARD,
KALAMAZOO, MICH.

PREFACE TO THE SECOND EDITION.

The first edition of this book was exhausted sometime since and numerous calls have been made for another edition. The book has been entirely re-written and much new matter has been added. An effort has been made to facilitate computations by Kutter's formula and tables of the value of *n* have been added to assist in a proper determination of its value for sewers.

The question of Sewage Disposal has also received attention.

PREFACE TO THE FIRST EDITION.

The subject of the sewerage of towns is attracting much more attention now than formerly. The reason for this is evident. While the country was new and the towns small and sparsely built, the disposal of the liquid wastes and other refuse was left to be provided for by each householder as he might deem best.

Various plans were employed, most of which were objectionable, and, in many cases, no plan at all. But as the towns increase in size and are more compactly built the question of a proper system of Sewerage forces itself upon the attention of the people. Some general system must be adopted for the whole town and the question is, what system?

The moderate cost of the "Separate System" makes it possible to carry out a system of sewerage in many cases where the expense of the "Combined System" would make the construction of sewers impossible.

One hindrance to the rapid introduction of the Separate System has been the lack of available information concerning it. Much has been written on the subject, but the necessary information is scattered in numerous pamphlets, reports and papers presented to scientific societies in the United States and in England.

The object of this book is to explain what the Separate System is, what it is designed to do, and to give practical

directions for designing and constructing sewers in accordance with that system.

No single design, however complete in all its details, will be best adapted to every case. Each town will present some features peculiar to itself and the general plan must be modified to suit the conditions of each case. All that is here attempted is to give sufficient theory, data and results of experience to guide in properly designing and constructing sewers on the Separate System.

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CHAPTER I.

INTRODUCTION.

"Sanitary Engineering" has been defined as that branch of engineering which has for its object the improvement of the health of towns and districts, by bringing to them a supply of those things which promote health, and carrying from them those things which are injurious to it.

The three principal requirements for the promotion of health are wholesome food, pure water, and pure air. An abundant and cheap supply of food is best secured by perfecting the means of transportation by land and water. Pure water may be supplied by suitable water works. The air is kept pure by removing from the districts those things which pollute it: that is, by removing all garbage, and by carrying out a proper system of drainage and sewerage.

Although all of these works contribute to the health of a district, yet the subdivision of labor in these times has increased the number of specialties in the engineering profession and has limited the field of the Sanitary Engineer. By common consent the engineer who plans and executes works for improving the means for transportation is called a Civil Engineer; the engineer of a system of water works is called a Hydraulic Engineer: leaving the Sanitary Engineer the task of removing from any locality whatever may be detrimental to health; thus assigning to him the role of scientific scavenger.

Man himself is the principal cause of the defilement of his surroundings. His presence brings pollution to earth, air and water. Nature provides a remedy which is efficient only to a limited extent. Refuse from the animal kingdom is food for the vegetable kingdom. But when human beings congregate in masses nature can no longer meet the demands.

In country districts, where the population is sparse, the disposal of excrementitious and refuse matter is easily managed by each householder in his own way. And even if that way be unadvisable the only sufferers are himself and those of his own household, and no one else will care to interfere. The methods usually there adopted, however, become very objectionable wherever the people congregate in large numbers. The conditions of living become changed. The sanitary condition of the immediate surroundings of each individual concerns not only himself, but the whole community in which he lives; and what was before a personal matter now becomes a question of public policy.

In all densely populated areas, as in large villages and cities, the disposal of the solid and liquid refuse becomes a serious problem. The Mosaic regulations (Deut. xxiii, 12–13) can not be enforced, and to store the filth of a city within the city is simply to invite disease and death.

The use of the pits, dug in the earth, as receptacles for refuse, is in every way objectionable. The soil becomes polluted with sewage, and the air is filled with the noxious gases arising from the sewage soaked earth, and from the putrefying masses in vaults and cess-pools. The decomposition of so much refuse in such close proximity to the dwellings is detrimental to health in two ways. It uses up the oxygen from the air, and loads it with pestilential gases. If cess-pools are used at all, they should be water tight. This necessitates the constantly recurring trouble of carrying away the contents when they fill up, and only partly removes the difficulty.

Need of Sewerage—An examination into the sanitary condition of a majority of our older cities and villages will show

the great need of some kind of sewerage. Many of them have never taken any measures to rid themselves of the necessary accumulations of filth, incident to a considerable population. For generation after generation the refuse which should have been removed far from the dwellings, has been flung upon the surface of the ground, or into cess-pools, where the putrefying mass poisons the air, and appeals in more ways than one for a remedy. "The offense is rank." On one of the principal streets in one of our oldest cities it became necessary to remove several small houses to erect a large building. The interior of the block was thus exposed to view, and it simply made apparent the state of affairs in nearly every block in the city. Within the space of 150 feet long by 50 feet wide, there were four wells and seven vaults and cess-pools. It needs no chemical analysis to determine the impurity of water obtained under such circumstances, nor a very vivid imagination to conceive the foulness of the atmosphere in that locality.

The earth upon which many of our cities stand is literally saturated with sewage. The vile odors which are exhaled from the polluted soil, and from the sinks of rottenness and putrefaction which it contains, contaminate the air in the streets, and are a constant reminder of the need of an efficient remedy. There they stand, reeking in the accumulated filth of past generations, never for a day free from malaria, and zymotic diseases; and yet the remedy is easily applied and the cost of it within the reach of the poorest hamlet.

Pollution of Streams.—A small water course running through a city without sewers is sure to become a nuisance. Every conceivable variety of filth and refuse will be thrown into it, and it will soon be simply an open sewer. In dry weather, when the flow of water is at its minimum, the bed of the stream will become an elongated, open cess-pool of the worst variety. The channel is sometimes cleared by throwing the accumulations of filth upon the banks: that is, the filth is spread over a larger surface instead of being removed. Periodical cleanings of the bed and banks of the stream will only mitigate the nuisance tem-

porarily. The cure must reach the cause of the evil if it is to be radical and entire. The sewage must be provided for in proper channels of its own, and only the storm water be allowed to run into the open water courses.

The following extracts are taken from a report of the State Board of Health of New York. The name of the city referred to is omitted, but the name of any unsewered city or village might be filled into the blank spaces and the report would give the actual sanitary condition in a majority of cases:

"Dr. Carroll's full report on the prevalence of filth and malarial diseases in ———, and the causes thereof, is well worthy a careful reading by every citizen of ———.

"The record is both sad and alarming. Sad, because it shows that at least one-fifth of the deaths in your city during the past year were clearly preventable by ordinary municipal provision for cleanliness; alarming, because the already abnormal death rate from filth poisoning must, from the very nature of the cause, steadily increase. ——— affords another of the many lamentable illustrations of the apparently ineradicable popular delusions that natural water courses are the proper receptacles for sewage and house refuse of all kinds. * * It appears from the report that the number of fatal cases from diphtheria, typhoid fever, diarrhœa and scarlet fever is, at least, three times as great as it should be under normal sanitary conditions. These diseases are known to be intensified, if not directly caused, by filth poisoning. The prevalence of malarial diseases is also reported. * * * There seems to be no doubt that there is a large amount of malarial trouble in ———. This disease is usually associated with surface or sub-soil saturation, occurring either immediately around dwellings or within such a distance that miasmatic emanations may be carried by the winds over an inhabited locality. There appear therefore, to be at least two prominent classes of more or less preventable diseases occurring in ———, one of them dependent upon conditions of filth and the other upon undrained or saturated lands. The nature of these two classes leads to the conclusion, that filth is accumulating within the city of ——— in such a way, and in such places, as to effect the public health, and that there are saturated tracts which produce malarial diseases.

"The first and most important measure to stop the present death rate from filth diseases in ——— is to provide proper means of carrying away the organic filth of the city. The use of open brook channels as sewers should be absolutely prohibited. They should be reserved for the drainage of surface water only. Such a prohibition can hardly be made effectual until some means are

provided for carrying the sewage away from the city. For this purpose a system of sewers is strongly advised, and little relief can be expected from the present unwholesome condition of the city until sewers have been built. * *"

Pollution of the Subsoil and of Wells.—The ordinary cess-pools are especially objectionable where wells are used as a source of water supply. A well is simply a hole dug in the ground, into which the water, which has sunk into the earth, may drain. The quality of the water will depend upon the condition of the soil through which it passes. In cities without sewerage, cess-pools by hundreds are formed in the earth, into which all manner of filth is thrown. Into this same soil wells are dug, and the drippings from the cess-pools are caught and drank, and the seeds of disease are sown broadcast in the community. One often hears it said that water which passes through the earth is filtered and purified. But it must not be forgotten that while the earth acts as a sieve, and removes the suspended impurities the oxydation and nitrifaction of organic matter depends upon circumstances which are not likely to be favorable very far beneath the surface of the ground. Whatever is in solution remains, to a large extent, in the water.

The Swiss village of Lausen, near Basle, is supplied with water from a spring, situated at the foot of a mountainous ridge, called the Stockhalden. In this village, where there had not been a single case of fever in many years, an epidemic of typhoid fever broke out, which struck down seventeen per cent. of the whole population. The cases of fever were pretty evenly distributed among the families in the village, with the exception of six. As the six families which escaped did not use water from the spring, suspicions were aroused concerning the water and investigations were made. It had previously been noticed that when the meadows in the Furlerthal—a little valley on the other side of the Stockhalden ridge—were irrigated, the volume of water in the spring was increased; and by the sinking of the soil in one of the meadows in the Furlerthal, a vein of water was discovered, which, it was supposed, led to the spring in Lausen. It was found, upon investigation, that a peasant living in the

Furlerthal had returned home from a distant city, sick with fever, and that the brook in which his clothes had been washed and into which the slops from the house had been thrown, had been used to irrigate the meadows. This water thus spread out over the fields and then filtered through the ridge, a distance of a mile, still carried the germs of disease in it, and brought death to the unsuspecting inhabitants of Lausen.

To prove, conclusively, that the spring was supplied from the Furlerthal, and to determine whether the water passed through an open vein or was filtered through porous material, the following experiments were made: Several hundred weight of salt was dissolved and poured into the hole in the Furlerthal, where the vein was discovered. In a few hours the water of the spring became very salt, and the connection between the water in the Furlerthal and the spring at Lausen was established beyond a doubt.

They now mixed two and a half tons of flour in water and poured it into the hole, but no trace of the flour could be found in the spring; proving that the water was so thoroughly filtered as to remove the minutest particles of the flour, and yet it still retained its infective properties.

Clearness is no proof of purity in water. The water of the Saratoga Springs, although thoroughly impregnated with various minerals, are as clear as ordinary spring water, and in a glass of water as clear as crystal there *may* be poison enough to kill a whole family; not only by the comparatively slow and uncertain process of fever, but surely and immediately. Deleterious gases may indeed add a sparkle to well water, and the peculiar flavor so highly prized in some wells may be borrowed from a neighboring cess-pool.

Dr. Victor C. Vaughn, Professor of Physiological and Pathological chemistry in Michigan University, states in a report to the State Board of Health, that a series of experiments which he has conducted confirms the germ theory in cases of typhoid fever. The fever was produced in a cat by inoculation and the

cat showed all the symptoms of the disease. In connection with this Dr. Vaughn states:

"Last August there was an epidemic of typhoid fever in the village of Iron Mountain, a place in Northern Michigan of about 4,000 inhabitants. Part of the town was supplied with water from a mountain spring, and part from private wells from six to twenty feet deep. It was noticed that all those who used the spring water escaped the disease, while those who depended upon the shallow wells were stricken down. In all there were many hundred cases and about forty deaths. I secured some of the water from these shallow wells and with it experimented upon a number of cats, finally obtaining the result which I announced to the Board of Health."

If, as Professor Vaughn states, these city wells contain fever germs enough to kill a cat, with its traditional nine lives, what chance is there for an ordinary human being with only one?

The following are the results of a very general examination of the water in wells in one of the most beautiful and well kept smaller cities in the state of New York. The natural drainage facilities of the city are excellent. There are no sewers worthy the name, however.

The results are particularly interesting, not only as showing the marked subsurface pollution within a comparatively few years, but also as showing the increased mortality directly resulting therefrom.

"I have made some chemical tests of water from nearly one hundred wells to determine, if possible, the extent of the pollution of the drinking water commonly used, and have made out a table which is given below of the results of these tests. The amount of chlorine which a sample of water may contain and not be regarded as unsatisfactory is usually assumed as 3.5 grains per Imperial gallon. I have drawn a line at this point across the list of wells below, and another at 7.0 grains per gallon, which last may, at least, be called the danger line if not the death line.

In the table with the analyses of the well water I have placed those of some other waters for comparison. No. 77 was urine diluted with 49 parts of pure water, Nos. 85 and 88 are from wells so situated as to drain large barnyards, No. 93 is from the outlet of the sewer which last summer was turned across Main St. and carried down Mill St., joining the Bacon Street sewer. I have also marked those wells used by families where there have been cases of fever and (generally fatal) cases of diphtheria with an "F" and a "D" respectively.

Number.	Source.	Chlorine as Chlorides grains per Imperial gallon.
1	Academy Filter	.25
2	Thayer Spring	.50
3	Rain	.55
4	Hazelton Spring	.70
5	Country Well	.80
6	West Main	.80
7	Country Well	.95
8	Lincoln Avenue	1.05
9	East Main	1.40
10	Wolcott	1.50
11	West Main	1.60
12	Wolcott	1.65
13	Lincoln	1.75
14	South (1 mile out)	1.75
15	East Main	2.00
16	Well in Pasture	2.05
17	East Main	2.15
18	Sewer, Lincoln	2.15
19	Spring in Pasture	2.35
20	West Main	2.40
21	Summit	2.50
22	Myrtle	2.50
23	St. Marks	2.65
24	Church	2.65
25	Wolcott	2.70
26	Main	2.70
27	Wolcott	2.95
28	East Main	3.00
29	West Main	3 20
30	Wolcott	3.30
31	Maple	3.40
32	Myrtle	3.50
33	Pond in Village	3.65
34	Myrtle	3.65
	Average of 9 Rochester Sewers (Dr. Lattimore)	3.78
35	Myrtle	3.80
36	East Main	4.00
37	South	4.00
38	East Main	4.10
39	East Main	4.25
40	West Main	4.25
41	Church	4.35
42	Myrtle	4.50
43	Myrtle	4.50
44	F	4.60
45	Lake	4.60
46	Main	4.65
47	South	4.65
48	D	4.75
49	Pond in Village	5.00
50	Church	5.00
51	Main	5.20
52	South	5.25
53	Lake	5.65
54	Lake	5.75
55	West Main	5.75
56	North	6.00
57	Clay	6.25
58	Church	6.25
59	Craigie	6.40
60	Clay	6.50
61	Wolcott	6.50
62	Sewer, East Main	6.55
63	D. F.	6.60
64	Mill	7.30
65	F	7.35
66	D	7.50
67	St. Marks	7.60
68	Bank	7.60
69	F	7.70
70	D	8.25

Number.	Source	Chlorine as Chlorides grains per Imperial gallon.	Number.	Source.	Chlorine as Chlorides grains per Imperial gallon.
71	Bacon	.480	85	Barn Yard Well	11.75
72	East Main	8.85	86	Dish Water	11.90
73	F	8.85	87	Myrtle	12.20
74	North	9.00	88	Barn Yard Well	12.75
75	D	9.10	89	D	12.80
76	South	9.60	90	F	13.65
77	Urine in 49 pts. water	9.65	91	F	15.00
78	Lake,	9.75	92	D	15.60
79	Lake	10.50	93	Sewer, Mill St	17.30
80	East Main	10.70	94	West Main	17.70
81	D	10.75	95	Bacon	19.05
82	St. Mark	10.90	96	Mill	19.80
83	D	11.05	97	East Main	25.50
84	Myrtle	11.30		Average 78 wells	6.56

The following table shows the results of the analysis of the water supplied to Schenectady, Troy and Albany. The Nitrites were reduced to nitrates and both appear under that heading. Ammonium salts are represented by organic nitrogen. The analysis was carried on under the supervision of Prof. Perkins. The numbers represent parts per 100,000 by weight.

ANALYSIS OF WATER.

No.	Sample.	Date.	Color.	Temporary Hardness.	Permanent Hardness.	Total.	Free Ammonia.	Organic Nitrogen.	Nitrates.	Chlorine.	Remarks.
1	Schenectady W. W......	April 25...	Clear	4.4..	7.5..	11.9	None...	.00400	.045019	.80	From Mohawk
2	Troy W. W.............	April 3....	Clear	4.3..	5.5.	9.8	None...	.00400	.040740	.50	
3	Albany W. W...........	April 3....	Clear	......	......	10.0	None...	.00500	.051028	.60	From Hudson
4	Albany W. W...........	May 17...	Clear	......	......	......	None...	.00500	.045530	.30	From Tiv. Lake
5	Lafayette St., Sch'y......	March 27.	Clear	......	......	34.0	None...	.00500	Not taken	11.30	
6	Lafayette St., Sch'y......	May 31...	Clear	......	......	34.0	None...	.00500	Not taken	14.00	
7	Lafayette St., Schen'dy..	March 30.	Clear	......	......	54.0	.012143.	.01500	3.337003	28.40	
8	Church St., Schenectady.	April 2....	Clear	......	......	......	None...	.00600	4.04400	18.80	
9	Jay St., Schenectady.....	April 17...	Clear	......	......	......	.004857.	None	.84070	4.40	
10	Albany.................	April 19...	Clear	......	......	12.7	None...	None	3.05031	8.00	
11	Park Place, Schenectady..	May 31...	Clear	......	......	......	None...	.00700	.831403	1.90	

Let us now look at these results and see what they indicate. The total hardness of the water supplied to the three cities is about the same, the difference being no more than would exist in the same water on different days. In permanent hardness the Troy water is much better than that of Schenectady. The nitrates indicate the sewage contamination perfectly, increasing as we go down stream from Schenectady to Albany. Above Schenectady there is very little sewage flowing into the Mohawk, till we reach Utica, eighty miles above, that being the only place on the river with a system of sewers. The river itself passes over many rifts and shallows between the places, affording every opportunity for oxydation of the organic matter. At Troy the river has received the sewage of Cohoes, Waterford, Lansingburgh, etc., and at Albany that of Troy and West Troy in addition, and nitrates accordingly increase. The Hudson river water at Albany has been condemned by the Albany Water Commissioner as unfit for use, and a new source of supply has been recommended.

Samples 5 and 6 were from the same well—No. 5 taken just before it was cleaned, No. 6 about six weeks after. There is a vault a short distance from the well, with which it is evidently in direct communication, the chlorine being more in the second analysis than in the first. No. 7 was furnished by a physician of Schenectady who was called to prescribe for a man sick with typhoid fever. He suspected that the cause lay in the water, though the man affirmed that it was the best water in the city. The analysis shows, besides ammonia, organic nitrogen, and nitrates in large quantities, an amount of chlorine nearly three times as great as that in common sewage.

In No. 8 the nitrates and chlorine were very high, especially the former. The well is only eighteen feet from a vault.

No. 10 was sent by a physician of Albany. He writes as follows concerning it:

"I send you a specimen of well water, which I think has caused three cases of severe illness, two of which were fatal. I was called some months after these cases to see a patient who had a high fever, (temp. 105°5, pulse 140,) with

diarrhœa and nausea, in whom I could find no disease of any organ to account for the fever. I stopped the use of the well water and she commenced to improve, and is now (two weeks) about well. Since I saw her she has been drinking filtered rain water. The well in this case is within ten feet of a privy vault, and the two have adjoined one another for twenty years."

Effect of Sewerage.—The beneficial effects of sewerage are plainly seen in the statistics of towns where an efficient system has been carried out. By sewering certain towns in England, the death rate from pulmonary diseases alone was reduced 50 per cent. A marked decrease in the amount of sickness and a prolongation of life has always followed proper sanitary works.

Below is a table showing the results of sewerage in six towns in great Britain:

NAME OF PLACE.	Average mortality per 1,000 before the construction of sanitary works.	Average mortality per 1,000 since completion of the works.	Saving of life, per cent.	Reduction of typhoid fever, rate per cent.	Reduction in rate of pulmonary disease, per cent.
Cardiff	33.2	22.6	32	40	17
Croydod	23.7	18.6	22	64	17
Macclesfield	29.8	23.7	20	48	31
Merthyr	33.2	26.2	18	60	11
Newport	31.8	21.6	32	36	32
Salisbury	27.5	21.9	20	75	49

"At Dantzic the deaths from enteric fever per 100,000 living were as follows:

From 1865 to 1869, before any sanitary measures were taken, 108.
From 1871 to 1875, after the introduction of water supply, 90.
From 1876 to 1880, after the introduction of sewerage, 18."

The death rate in London in the last half of the 17th century was eighty in every thousand. Now it is about twenty-four in every thousand, although much more densely populated.

Irwin F. Smith, in a very comprehensive paper on the "Influence of sewerage and water supply on the death rate in cities," writes as follows:

"Data drawn from sewered cities is now available for study and comparison. To be of service such data must have been carefully gathered and must cover a considerable period, the population must be known to have been correctly enumerated, and various other factors which enter into every consideration of the death-rate of a place, such as race, age, condition in life, crowding, occupation, etc., must be given due weight. Taking all these factors into consideration, and casting up accounts, there remains a striking balance sheet in favor of the sewered cities.

In the consideration of this subject the general propositions which I wish to lay down, and which appear to me to be clearly deducible from the data at my disposal are as follows:

"Typhoid fever and cholera decrease in proportion as a city is well sewered. This may be laid down as a fundamental proposition to which there are no exceptions.

"The general death rate falls after the sewering of a city, and, other things being equal; never again reaches the maximum of its ante-sewered condition.

"The cost of building and maintaining sanitary works is inconsiderable in comparison with the direct pecuniary loss, by sickness and death, which their absence entails.

"Drains imperfectly jointed and lacking the proper facilities for flushing or the necessary fall for the introduction of excreta and for proper clearing, are in no proper sense of the word *sewers*, and are not considered as such in this paper. If excreta be introduced into such drains it almost always proves a public nuisance, and the writer is far from denying that under some circumstances such drains, "sewers," so-called, may not become active promoters of infectious diseases. When I speak of the benefits arising from sewerage I mean, invariably, modern sewers, well built, well ventilated—the soil-pipes, traps, water-closets, etc., being constructed on approved plans and in the most workmanlike manner.

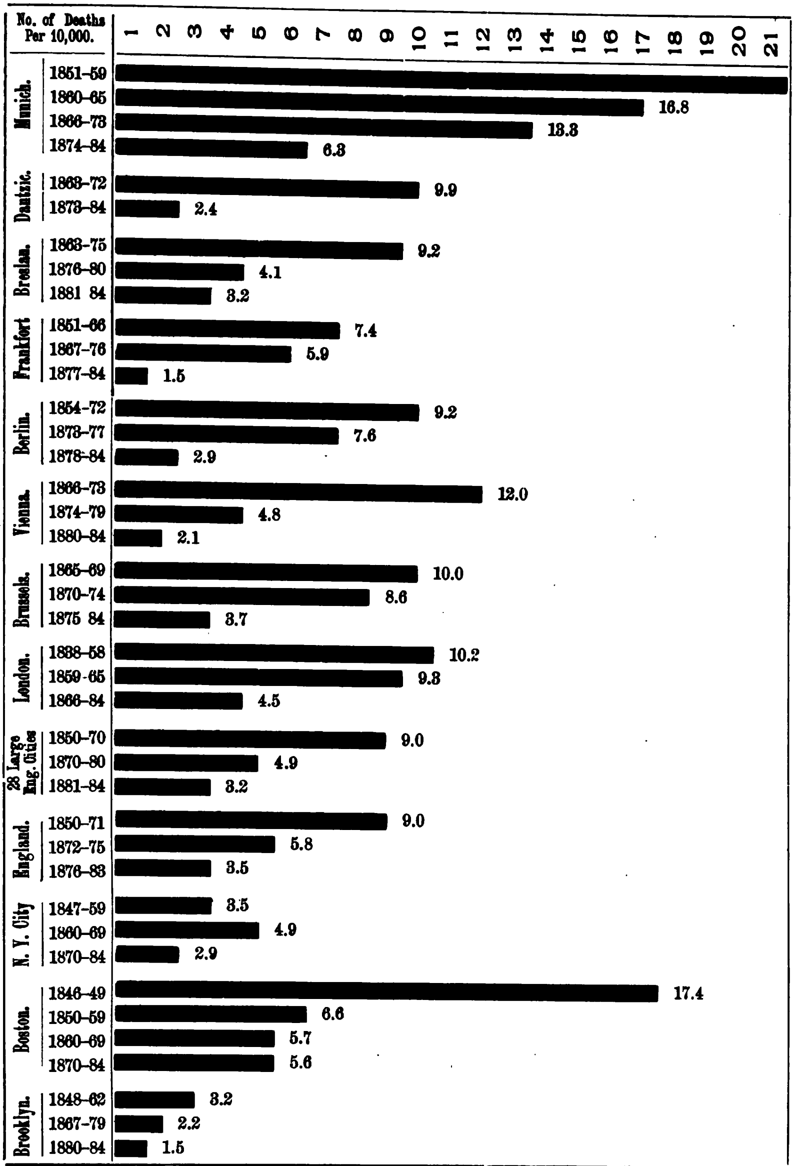
My reason for selecting typhoid fever is that, although the nature of the typhoid poison is yet in dispute, we now understand very clearly the manner in which the disease is spread. Another reason is the gravity of the mortuary tax levied by typhoid fever. This will be at once apparent if we consider briefly the statistics of this disease."

The following graphical presentations of some of the statistics collected by Mr. Smith are reproduced from his paper.

DEATHS FROM TYPHOID FEVER TO EACH 10,000 INHABITANTS

BEFORE, DURING AND SINCE THE

INTRODUCTION OF SEWERAGE AND WATER SUPPLY.



DEATHS FROM ASIATIC CHOLERA IN AMERICAN AND EUROPEAN CITIES,
DURING THE EPIDEMIC OF 1865-6.

Designed to Show the Protective Influence of Sewerage and Water Supply.

The cities of GROUP I. were abundantly supplied with good water, and in most cases were also well sewered.

The cities of GROUP II. were incompletely sewered, or entirely destitute of modern sewers, and very dirty. Their water supply was scant or open to infection, being generally very deficient both in quality and quantity.

	YEAR.	LOCALITY.	DEATHS PER EACH 10,000 INHABITANTS.
I.	1866	NEW YORK	12.8
	1866	BROOKLYN	16.5
	1866	BOSTON	0.6
	1866	LONDON	18.4
	1866	GLASGOW	1.6
II.	1866	NEW ORLEANS	72.7
	1866	ST. LOUIS	173.0
	1866	CHICAGO	43.7
	1866	CINCINNATI	62.0
	1866	MEMPHIS (Tenn.)	268
	1865	MARSEILLES	64.7
	1865	TOULON	200.9
	1866	NAPLES	76.7
	1866	PALERMO	197.5
	1865	MADRID	92.4
	1866	ST. PETERSBURG	97.8
	1865	BRUSSELS	163.7
	1866	BRESLAU	257.3
	1865	CONSTANTINOPLE	133.0

Schenectady, N. Y., was sewered in 1884. The Health Officer, H. C. Van Zant, in his report for 1887 writes as follows:

"I remark this fact: in 1883 twenty-six deaths occurred from typhoid fever; 1885, eighteen deaths occurred from the same cause; 1887, five deaths are recorded as produced by typhoid fever. More deaths in 1883 than cases in 1887. The inference is easy."

The desirability of the removal of filth from cities is no longer a matter of doubt. The beneficial effects of a proper system of sewerage is proven by abundant statistics. The results are shown in a decrease of disease, a lowering of the death rate, and in turning plague smitten cities into healthful ones. The question no longer is, *shall* it be done? but, *how* shall it be done?

Systems in Use.—The different systems for the removal of excrement and liquid refuse may be divided into three classes, viz.: by "Direct Removal," by the "Pneumatic System," and by "Water Carriage." Under the head of "Direct Removal," the principal methods are the "Pail System" and the "Dry Earth Closet."

In the Pail System the excreta is caught in a pail or tub and removed in carts at intervals, varying from one day to a week. This system is used in many large cities in Europe, and is advocated by eminent authorities. But the exchange and cleansing of the pails need to be enforced by such strict police regulations as would be difficult to carry out in the United States. There are several modifications of the Pail System. In one, the fluids are allowed to filter through a sieve and run off into the sewers provided for the storm water, so that only the solid matter is carried away in the carts. In another the tub is lined with some material, which acts as an absorbent and deodorizer, as in the Goux system.

When the Dry Earth Closet is used, dry, powdered earth, or ashes, is added to the excreta in sufficient quantities to absorb the moisture and deodorize the whole mass. So much care and attention is necessary to provide a proper supply of dry earth, to apply it properly, and to attend to its removal, that it can only be used in exceptional cases, and cannot be relied upon for general use.

To obviate the difficulty of the frequent exchanges and constant supervision necessary to the successful operation of the Pail System, water-tight cess pools are sometimes used. They are made large enough to hold the sewage for a considerable time, and when filled the sewage is carried away. The nuisance of emptying them is somewhat abated by the use of a large, air-tight iron tank, mounted on wheels. The air is exhausted from the tank, and by making a pipe connection between the interior of the tank and the sewage in the cess-pool, the contents of the cess-pool are forced by atmospheric pressure into the tank; or, the sewage may be pumped from the cess-pool into the tank.

The three principal "Pneumatic Systems" are: the "Liernur," "Berlier," and "Shone."

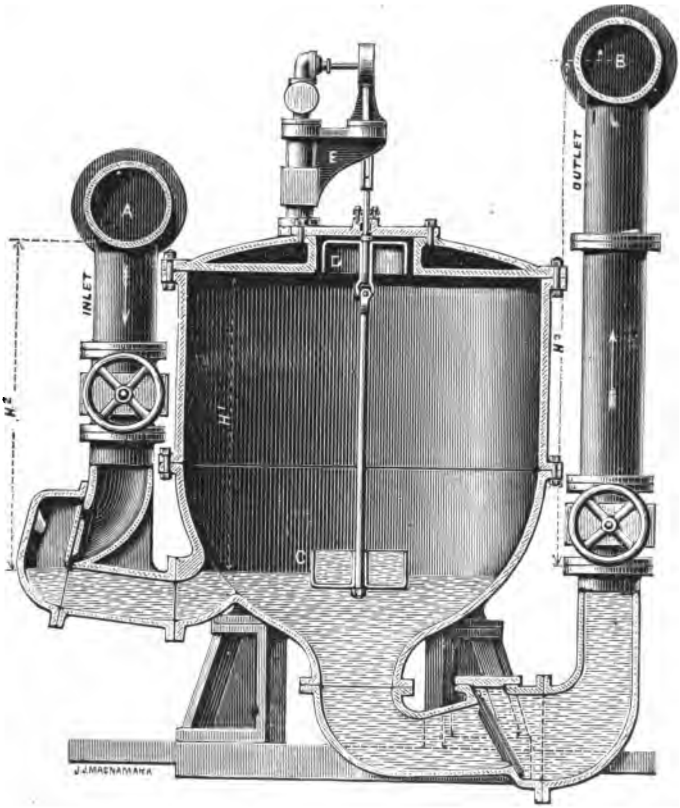
The Liernur and Berlier systems consist essentially of a network of air-tight iron pipes, through which the excrementitious matter is drawn, by exhausting the air from the pipes by means of large air pumps.

These systems are intended to dispose of only that part of the household wastes which is most valuable for manure. Separate conduits must be provided for the foul liquid wastes from dwellings, factories, etc. The necessary plant and appurtenances are very expensive, and even then these systems only partly answer the purpose of sewers.

The prominent feature of the Shone System is the use of compressed air for the purpose of raising sewage from a low level to a higher one. It is especially valuable in towns where sufficient fall for sewers cannot be obtained. In this plan the sewage is conducted through pipes in the ordinary way until it becomes necessary to carry it to a higher level. It then flows into a large iron tank, called a "Pneumatic Ejector." (See cut). When the Ejector is full, compressed air is automatically applied to force the sewage into pipes at a higher level, where it is again allowed to flow onward towards the outfall under the influence of gravity; or, the compressed air may be utilized to deliver the sewage from an outlet below the low water level. The air is compressed by steam, or water power, at a central station and is led by pipes to

the Ejectors, so that they can be placed in any convenient situation, and as frequently as the case may require.

The Shone Ejector takes the place of a pump for raising sewage, and can be used with great advantage in situations where it would be difficult to bring the sewage to one pumping station.



The Shone System has been mainly used in England. It is applied to a limited area in Chicago, however, there being two Shone Ejectors, with a capacity of 600 gallons lifted fifteen feet per minute each, intended to raise the sewage from a thirty-six inch sewer, designed for house drainage only.

All of the systems of direct removal require constant care and attention, and only partially accomplish the end in view. They are better than no system, but are not as efficient or as easily managed as the method of "water carriage" or sewerage. Water is the great scavenger. It cleanses our houses, our clothes, our food, and ourselves; and having once been soiled it must be gotten rid of. In doing this the water may be made the vehicle for carrying away excrementitious matter, which would, by putrefaction, vitiate the air and tend to produce disease.

In the Pneumatic Systems costly machinery is necessary to provide for carrying away only a portion of the refuse which should be disposed of, and the expense of operating is large and constant.

The Water Carriage System is most favored by the leading English, German, French and American sanitarians.

"As ordinarily managed the earth closet and all other conservancy methods become a nuisance, only to be tolerated when sewerage proper cannot be secured."—*Irwin F. Smith.*

"I do not say that a well managed conservancy system is not better than a badly managed one, nor far better than no system at all, nor do I say that there are not places where the difficulty of carrying out a Water Carriage System is not so great as to be almost, if not quite, insurmountable; but I do say that in towns where a Water Carriage system is possible, there is no room for choice in the matter."—*Corfield.*

In the Water Carriage System all that is needed is a comparatively inexpensive conduit which provides for all of the sewage; and if properly constructed the cost of maintenance is trifling.

There are many cities which have provided themselves with an abundant supply of water, and yet have made no provisions for a system of sewers. Increasing the water supply without providing for its outflow after it has been fouled, only makes a bad matter worse. The number and size of the cess-pools must be increased. Instead of draining the soil, as common sense would dictate, additional water is poured into it by the millions of gallons, and year by year the soil is more thoroughly soaked

with sewage. The streams of filthy water which may be seen running in the open drains, leading from back yards into the streets, tell a story which all can read, and the effects of this state of affairs can be plainly seen if the Health Officer makes full reports.

One of the twelve tasks imposed upon Hercules was to cleanse the stables of Augeas. In these stables vast herds of cattle had been kept for many years, and they had never been cleaned. He accomplished the task by turning a stream of water through them. This famous exploit—"cleansing the Augean stables"—is repeated over and over again wherever abundant water supply is supplemented by thorough sewerage. Had Hercules only planned to bring the water into the stables and made no provision for its outflow, the project would have been a miserable failure, and the sensible people of that day would have called Hercules a fool; and yet there are cities even in this enlightened age where such a plan has been pursued.

"The yearly discharge from the sewers of Brooklyn equals in volume what would fill the entire streets and avenues of the city to a depth of twelve feet above the pavement or three feet over every parlor floor in the city. Such is the amount of work silently going on beneath our feet, of which we take no note save when it is interrupted."—*Adams.*

CHAPTER II.

WATER CARRIAGE SYSTEMS.

A theoretically perfect sewer would be one in which all of the sewage would be carried rapidly to its outfall outside of the city, so that no time would be given for decomposition. The conduit itself should be smooth, impervious to water, and should be water-tight throughout its entire length. It should be flushed at intervals, and so thoroughly that the development of any considerable amount of sewer gas would be impossible.

It should be so well ventilated that the small amount of sewer gas which might unavoidably be generated in the sewer would be so diluted with fresh air as to be rendered harmless.

It should be provided with ample means for inspection and repair.

It should be automatic in its action, so as to require the least possible amount of care and attention.

One of the first questions which presents itself to the engineer in planning a system of sewers is, whether the sewers shall be made large enough to carry the storm water as well as the sewage, or the sewage only. When a system of sewers is designed to carry both the storm water and the sewage, it is called the "Combined System." When the system is designed to carry only the sewage proper; that is, the liquld refuse from dwellings, factories, etc., it is called the "Separate System."

The Combined System.—The large sewers of the Combined System are usually built of brick. The brick being porous, allows more or less of the sewage to escape into the soil, even if every joint is water-tight, which is never the case. The rough surface of the bricks soon become covered with a slime of organic matter, which is constantly decomposing. In

designing sewers on this system the size will be determined mainly by the amount of rainfall per hour during storms, and the surface to be drained. The volume of rainfall to be provided for is so much more than the sewage, that the amount of sewage scarcely enters into the computation.*

It is readily seen that ordinarily the sewage will be but a trickling stream in a sewer large enough to carry the storm water. At the street corners are catch-basins into which the storm water passes on its way to the sewer. Here the sand and rubbish, carried along by the current from the street, is supposed to settle and remain in the basin, while the water passes through a trap into the sewer. In the rush of water during a storm, however, a considerable quantity of the material which is supposed to remain in the catch-basin is carried on into the sewer, and this, with other foreign substances, introduced into the sewer either by accident or malice, settles on the bottom. These obstructions form a series of small dams in the sewer, and in dry weather the sewage stands in a succession of pools along the sewers, decomposing and sending volumes of sewer gas out of every crevice through which it can escape.

The great size of the conduits of the Combined System, it is seen, is detrimental to their efficiency in removing sewage rapidly and completely; and yet, for the purposes for which they are supposed to be designed, they are seldom large enough. Even where vast sums have been spent to construct the Combined System of sewers, it is seldom if ever, that they will carry the water of great storms. In many cities—notably Chicago and London—where money has been poured out without stint, and millions of dollars have been expended for sewers of great size, the extraordinary storms are not provided for, and the consequence is that the sewers overflow, and cellars and basements are flooded with sewage. Where the storm water is excluded from the sewers, or only a definite amount admitted for the purpose of flushing, no such disaster can occur.

*See chapter specially devoted to this subject.

The difficulties of properly flushing and ventilating large sewers are almost insurmountable. Many devices have been proposed for ventilation. Some have advocated high chimneys with a fire in them to produce a draft. Others, a shaft with a screw or fan, for producing a current. None of these plans have proved efficient, and there seems to be no way of disposing of the gas except to let it out into the street by openings from the sewer to the pavement. In any dry season, when there is the least amount of sewage and, therefore, the most sluggish flow and the greatest evolution of gas, the water evaporates from the catch-basin trap and there is nothing to hinder the escape of gas into the streets. The catch-basin itself, unless kept clean, soon becomes a cess-pool, charged with filth from the streets and gutters, which soon decomposes.

The flushing cannot be very thoroughly accomplished, owing to the rough interior surface of brick sewers, and to the large amount of water necessary in the large sewers. The most that can usually be done is to produce current enough to carry forward and out of the sewer the solid matter and rubbish, which would obstruct the flow of the sewage. Sometimes the sewage itself is stored up until a sufficient volume is collected to flush the sewer, when it is released.

These points are so well brought out in the annual report of O. W. Wight, A. M., M. D., Health Officer, Detroit, Mich., to the Common Council, that we quote quite fully from his report:

"Ditches, gutters, tiles and porous brick conduits for removing surface and subsoil water are comparatively cheap. It adds immensely to the cost to transform water drains into sewers, so as to make them at all fit to convey liquid wastes. The combined expense of a separate drainage system and an independent sewer system is much less than the expense of a single system that cannot be so constructed as to perform well the double service of removing water from the soil and liquid from habitations.

"In most places it is not difficult to find a proper out-fall for the water of a drainage system. As soon as sewage is mixed with the flow of drains the whole mass is contaminated, and the trouble and cost of securing a safe outfall are, as a rule, greatly increased. The necessity of pumping vast quantities of rain water and subsoil water, mingled with the liquid refuse of houses and

factories in the same system in the new sewerage works of Berlin and Dantzic, increases the running expenses to an extent threatening failure.

"The sewage proper of a city is nearly a constant quantity. It is approximately measured by the amount of water daily used in houses and factories. Consequently, the engineer in constructing a system for the removal of sewage proper, can adapt it to a constant flow and make it self-cleansing. On the contrary, rain-fall is an immensely variable quantity. A drainage system for its removal must be of maximum size. When sewage, therefore, is turned into the drainage system, a slow flow will be inevitable much of the time, resulting in putrefaction and the generation of sewage gas, the presence of which within the area of inhabited places dangerously violates the most vital law of sanitation.

"In the drainage system all conduits are purposely made to let water in. The object is to convey water away from the soil. But a porous drain will strain sewage through into the earth, and gradually pollute it. Consequently, a conduit for the conveyance of sewage must be made tight. Hence the absolute incompatibility of the two ends sought in the same structure. A good sewer is a bad drain. A good drain is a dangerous sewer. Attempts are constantly renewed to attain the double quality of perviousness from without and imperviousness from within, with unceasing and inevitable failure. Sanitarians who are quacks in engineering have tried it in vain; engineers who are quacks in sanitation have tried it equally in vain. Quacks in both engineering and sanitation, sometimes well represented in City Boards of Public Works, obstinately keep up their search for the unattainable, like the seekers for the philosopher's stone and the inventors of perpetual motion.

"Water stored in cisterns is almost invariably poisoned by the way of overflow pipes which discharge into the sewer system of inhabited places and return the dangerous gas. And the drain pipes from cellars and basements generally furnish avenues through which this invisible foe of human life in cities finds easy ingress to habitations. A separate drainage system affords an easy means of guarding against peril from such a source. Sanitary inspectors are often astounded by finding a tube from an ice box, in which choice and delicate food, like meats and milk, is kept, running directly into a sewer pipe. The combined sanitary and engineering quack will tell you, with pitiful ignorance, that the deadly sewer gas is kept out by means of a little-water trap through which a baby could blow with a straw. A separate system, used exclusively for sewage, is the only certain safety against such danger.

"With the clumsy, costly, perilous Combined System in general use for removing water and sewage together, the earth of towns gradually becomes infected with organic matter in a state of putrescence. Hence the water of springs and wells at length becomes polluted and unfit for use. With a separate, properly-constructed and properly managed system of impervious pipes for the removal of all sewage, and with other sound sanitary regulations for the

care and removal of solid organic refuse, there is no reason why the spring water and well water in towns should not remain clean and wholesome. Besides, when the earth of inhabited places is kept so clean as to preserve the purity of the water, no exhalations will arise from it deleterious to health and dangerous to life.

"This is not the place to describe in detail the separate sewer systems for the removal of liquid organic wastes from inhabited places. The engineer must conform to the requirements of sanitary science. Any system will be faulty which allows sewage to putrefy at all, either in its source, on its journey from human abodes, or in its outfall. * * * * The great principle to be kept in view is the removal of sewage (not sewage diluted with vast quantities of surface and subsoil water) without pollution of the soil, without putrefaction, and consequently without generation of sewer gas on the journey. * * * The soil where man dwells is sacred, and it is sanitary sacrilege to pollute it. He who fouls the air that he breathes himself, or the water that he drinks, or the food that he eats, is a barbarian who might learn wisdom from the cat or decency from any swine not demoralized by contact with man. He who fouls the air that another must breathe, or the food that another must eat, or the water that another must drink is a criminal, to be classed with those who maim and kill.

"There are more reasons for such care in the removal of organic wastes from inhabited places than appear on the surface. The chemistry and hygiene of putrefaction are complex, involving many practical considerations. Wherever there is a collection of putrefying organic matter, whether on the ground, in the ground, within a faulty sewer, or under a habitation, there is a tireless foe to health and life. Not only are putrescent collections of garbage, decaying vegetables, manure, offal and human excreta harmful in themselves, by reason of exhalations poisoning the air and leeching liquids polluting the earth; they are also depositories and multipliers of disease germs. Such collections may not produce infectious diseases *de novo*, but they lessen the vitality of people living in the neighborhood, and thereby lessen the power of resisting epidemics. It is a well known pathological fact that nature struggles to eliminate disease by excretory processes. Accumulations of filth containing excreta may, therefore, harbor seeds of various communicable maladies. Sewer gas, while it may not beget scarlatina, diphtheria, smallpox and other contagious diseases, easily becomes the vehicle of conveying them, through obscure and intricate channels. * * * A foul sewer, swarming with scarlatina germs, may be more dangerous to a neighborhood than an infected school-house. * * *

"It has been objected in relation to separate systems for drainage and the removal of sewage, that droppings of horses and other animals in the street, steeping in the rain-fall, will be a source of pollution to surface water, rendering it putrescible and, consequently, capable of generating sewer gas. The

simple and effective remedy is cleaning the streets frequently and well. Most cities would thereby be greatly improved, both in appearance and salubrity.

"It has also been objected, that, in quarters where the vitrified sewer pipe system for the removal of sewage does not extend, there the inhabitants must throw the liquid wastes of household life upon the ground. No such necessity exists. Even an isolated habitation in the country should have its sewer pipes, and entirely separate from the drainage system, to convey kitchen slops, wash-water and other dangerous liquids to a place of safety. The reason why typhoid fever, diphtheria, and some other filth diseases are so prevalent in country districts, is that privy vaults so frequently seep into wells, and animal excreta of pig pens and stables are left to poison the earth and the air. The ground about kitchens, super-saturated with slops, very often becomes putrescent in the summer warmth, breeding disease which superstitious ignorance attributes to Heaven. A householder may dispense with his parlor and its adornments, if necessary, but he cannot afford to invite upon himself and family disease and death by neglecting to provide the means of keeping the site of his habitation dry and clean. *Laborare est orare*—'to labor is to pray'—said the wise old monk, and the most effective prayer for health is to supply every needed hygienic device for the sacred home of the family.

"It is further objected that most of the cities are sewered for the double purpose of removing storm water and sewage through the same conduits, and that we cannot afford to do the costly work over again. It is one of the fates of Progress that faulty methods must be followed by reconstruction. No works last forever, and when we build anew we can do it better. In the meantime the faulty sewers, with their dangerous debouchement into the nearest stream, lakes, or ocean harbor, can be washed out, disinfected, and used exclusively for water-drainage while a supplementary system, with safe out-fall, for the removal of sewage alone, is constructed with proper engineering skill under the direction of sanitary science. The cost of such a supplementary system is not more than one-fourth of that of the prevailing system."

Subsoil Drainage.—In some instances it will be necessary to lay special drains for the removal of ground water. It will be found, however, that often the strata are so broken up by digging the trench for the sewer and refilling it that the level of the ground water will be materially lowered. This is especially the case when the soil is made up of alternating strata of pervious and impervious material with an inclination unfavorable to the escape of the ground water.

Nothing connected with designing and building a system of sewers calls for more discretion on the part of the engineer than

proper provision for the ground water. It has frequently happened that long lines of sewer laid beneath the line of saturation have proved to be practically useless from lack of a proper conception of the influence of ground water and lack of proper methods for its removal or exclusion from the sewers proper.

The subject of subsoil drainage will be considered more at length in a subsequent chapter.

CHAPTER III.

THE SEPARATE SYSTEM.

The object of the Separate System of sewers is the complete removal of the sewage proper from towns, in such a manner as shall best subserve the convenience and health of the inhabitants.

To accomplish this object in the most satisfactory manner three things are required, viz.: constant and rapid flow of the sewage, thorough flushing, and adequate ventilation

Whatever tends to promote either of these three requirements is advantageous to the system and should be adopted. We will, therefore, consider what method of construction and combination of appliances will best attain the end in view. It is evident that to increase the size of the sewers, so as to make them large enough to carry the water of occasional storms, would be detrimental to the efficiency of the sewers, inasmuch as the ordinary flow would be impeded and retarded, and thorough flushing and ventilation made more difficult, if not impossible.

In a majority of cases the storm water can, without causing trouble, run in the surface gutters and ditches until it reaches the natural water courses. Only in large cities, where the water would need to run long distances through the streets, would any underground conduits for storm water be necessary. Where this is the case, either the sewer may be sufficiently enlarged for that purpose, or a separate channel may be provided for the storm water. The necessary length of these storm water sewers will, in any case, be but a small fraction of the whole system.

Roof Water.—On the other hand, if the introduction of a certain amount of roof water into the sewers will insure their thorough flushing whenever there is a sufficient shower, advantage should be taken of such ready means for accomplishing so desirable an end.

The object being, not the disposal of the roof water but the flushing of the sewers, no more roof water should be used than is sufficient for that purpose; and the engineer must carefully determine at what points, and in what quantities, the roof water may be introduced.

Size and Material.—The discussion in a subsequent chapter of the amount of sewage per capita which it is necessary to provide for, and the carrying capacity of pipes, will show that the commonly received notions concerning the required size of sewers are entirely erroneous.

In a majority of cases the people's money is spent in building large sewers, when smaller ones would be more efficient and cost very much less.

Having determined the amount of sewage to be provided for, and the size of conduit necessary, the next step is to determine the material for the conduit. Up to 18 inches in diameter the best material is glazed, vitrified earthenware. It affords a smooth surface for the flow of the sewage, and is durable and cheap. Above 18 inches, sewers of brick, laid in hydraulic cement are preferable.

Flushing.—While the problem of flushing the small sewers of the Separate System is a much less difficult one than that of flushing the large sewers of the Combined System, still the matter is of the highest importance and should receive the careful attention of the engineer. Any of the methods made use of in the Combined System can be more easily employed in the Separate System, as a much smaller quantity of water is required. With the ordinary flow of sewage in the pipes a fungous growth appears attached to the pipes beneath the flow line. This collects the sediment and slime from the sewage, and retards the flow. Even in pipes, which are apparently in good condition, a careful examination will disclose the fact that the surface of the pipe under the sewage is foul, and rapidly going from bad to worse. A rush of water will detach the fungous growth, and with it all of the filth which it has collected, and will carry it on to the out-fall.

Let any one examine a sewer which has not been flushed for several days. At first glance he will, perhaps, see nothing amiss. All seems to be in good order. But then discharge a volume of water into the sewer, sufficient to nearly fill it for several yards. The flakes of fungus and the black shiny clots of putrefying organic matter, which will be driven along by the rush of water, will disclose how rapidly the sewers grow foul with a quiet, even flow of sewage in them, and how essential the provision for frequent and thorough flushing.

If the rain could be relied upon to come at regular intervals, the problem of flushing would be readily solved. All that would be necessary, would be to provide for the discharge of the requisite amount of roof water into the sewers. But, unfortunately, there may be weeks without rain, and during these seasons of drought some means must be employed to supply the lack of rain water. This may be done in several ways. A flush tank mounted on wheels can be used, and this is available in towns without water works. In towns provided with water works the flushing can be done directly from the water pipes, or by means of automatic flush tanks.

Ventilation.—The ventilation of sewers has always been a difficult problem for the engineer, and especially is this the case where the Combined System is used. In the Separate System, properly constructed, and where ample provision is made for flushing the problem is much simplified. If only fresh, running sewage is found in the sewers, and there is no place where the sewage can stagnate and decompose, there will be very little sewer gas developed. If, in addition to this, the sewers are regularly and thoroughly flushed, the air in the sewers will be so frequently changed that there is less to be feared from them on account of sewer gas, even without any special arrangement for ventilation, than from the Combined System, with the most elaborate appliances for ventilation. Besides the ventilation secured on the street lines through the man-holes, lamp-holes and flush-tanks, a still more effective means of ventilation may be obtained by

carrying the pipes of the house drains, untrapped, up above the roofs of the houses.

We quote the following from Dr. Alfred Carpenter in the *Journal of the Society of Arts*:

"If a sewer flushes clean, as it ought to do; if it does not become the habitat of sewerage confervoid growths upon its invert; that is, if it is regularly scoured above, as well as below the line at which the sewage ordinarily runs; if there is nothing to intercept the passage of sewage from its origin to its departure at the outlet, then there will be no sewer gas, there will be no stink, there will be no danger to anybody.

"The openings on the inverts of the arch of the street sewer will be inlets for fresh air, and the ventilators produced by the extension of the soil pipe of every water-closet above the level of the house top will be outlets for the air which has passed through the sewer. Thus a constant circulation will be promoted at all times by the ordinary laws which belong to gases, and which by their very nature prohibit stagnation in fluids of all kinds. Occasionally there may be down draughts, but they will be of no more moment than the down draughts through an ordinary chimney—indeed they will be as infrequent as a down draught into a furnace when the fire is low. Fresh sewage is not dangerous to anybody, but if it is kept within the curtilage of the dwelling house by means of interceptors, or if it be allowed to stagnate in a badly constructed sewer until fermentative changes have arisen within its substance, it then produces the chance of evil; but in the present day no authority ought to be allowed to keep sewage within its borders until such a change has taken place. It should be "moved on" out of range as rapidly as possible. The house is the unit of sanitary work, and it is wrong for selfishness to assert itself so as to determine that no man shall assist the local authority in its duty to provide for sewer ventilation.

"I utterly object to the principle which is being tried to be established by various supposed authorities, viz.: that the duties of the individual are antagonistic to the duties of the local authority in the matter of sewers. If each unit does his part, the duty of the local authority as to ventilation is simple. The latter has to convey away the sewage, and provide inlets for fresh air. The outlets must be at the highest points, and if they are so placed, there will not be a particle of danger from the production of sewer gas. An authority has an important duty to perform, viz.: to prevent the production of sewer air, as a major part of its work. The provision for its escape, if it does accidentally form, will be best met by details in the construction of the house drain. Concentration should not take place, and without concentration sewer gas is perfectly harmless. There will be no diffusion of enthetic germs, for they cannot live in fresh air long enough to spread infective disease, and if, perchance,

a few should be discharged in the higher regions above the heads of a great or small community, they die in a very few seconds.

"The germs which produce enthetic disease cannot live in fresh air, any more than a fish can live in unaerated water. If discharged they should be diffused above the heads of the people, and not at the street level. These are my reasons for advocating the extension of every soil pipe, so that each water closet has a ventilator in action, and by this means properly constructed sewers will admit fresh air at the street level; and under common conditions, foul air, if produced, will escape, where it will fail to set up even the smallest possible danger. I advocated this principle twenty years ago, and experience, since my first paper upon this subject, has amply proved that I am right."

There are two methods of carrying out the plan advocated by Dr. Carpenter. One is by carrying the soil pipes up through the house so that they may serve also as ventilating pipes, and the other is by carrying a separate ventilating pipe up on the outside of the house. Both of these plans will be considered in detail in a subsequent chapter.

Special Features.—The Separate System of sewerage is not new and untried. It has been advocated by sanitary engineers for nearly half a century, and the arguments for its adoption have been presented in many forms. It was first used in England. It is in successful operation in many towns in the United States, and is rapidly growing in popularity as it is better known and understood.

The separation of sewage proper (house sewage) from the storm water falling on pavements, roofs, areas and lawns has been much more complete in the United States and Canada than in England.

It is but a decade since the introduction of the Separate System in the United States on any extended scale. During this short time probably about 500 miles of sewers have been constructed on this system in the United States and Canada and it is probable that it is in operation in about 50 cities and villages.

The plans employed in the different cities where it has been adopted are similar in general design, but differ in the details. The different conditions met with in the different localities would require a certain amount of variation, and each engineer has

followed his own methods for solving the problems which presented themselves. The following examples will show how the plans vary in different places:

In the sewers of Memphis, Tenn., designed by Geo. E. Waring, Jr., all storm water was excluded, and a Field's flush tank was placed at the head of each branch sewer. The sewers are ventilated through the untrapped interior house drains and ventilating pipes. Man-holes were generally omitted. Drain tile was laid in the same trench with the sewers.

In the sewers of Pullman, Ill., designed by Benezette Williams, C. E., the sewers are flushed by connections with the water mains, and the house drains are flushed by automatic flushing basins. Man-holes were placed 160 feet apart on the mains and 200 feet apart on the laterals.

In the sewers of Binghampton, N. Y., designed by Rudolph Hering, roof water is used for flushing, and in part of the system the sewers are made large enough to carry the storm water.

The details of the plan adopted for the sewers of Schenectady, N. Y., and the methods employed in their construction are similar to those described in the subsequent chapters. A Van Vranken flush tank is placed at each dead end.

The sewers of West Troy, N. Y., are mainly the Separate System. Certain portions of the city, however, are relieved from storm water through main sewers, which also serve as mains for the separate system. Certain portions of the city where the volume of ground water was large are also relieved by tile drains, these are ordinarily laid parallel with the sewers in the same trench and in most cases discharge into man-holes.*

In the city of Dayton, Ohio, the sewers are mainly on the Separate System as shown by the map on a subsequent page. The storm water is removed mainly through surface gutters. In some cases, however, there are underground conduits.

The sewers of the Separate System in Dayton vary from forty-two inches in diameter to eight inches in diameter. Man-holes are

* See map of West Troy.

placed at all junctions and on long blocks one is usually placed midway. All dead ends are provided with automatic flush tanks.

A considerable portion of the city was formerly subject to overflow from which it is now protected by a levee. The entire system of sewers on the east side of the Miami river converge at a point near the levee at which there is a pumping station of a capacity of about twenty million gallons per day. The sewage is at present discharged into the Miami river. The pumping station, however, commands considerable area of low lying land which, should future conditions dictate, can be utilized as a sewage farm.

It is evident that the Separate System is especially applicable where, for any reason, sewage must be pumped; or where it is to be purified by any of the many processes for that purpose; or where the sewage is utilized on a sewage farm. In all of these cases the exclusion of the storm water from the sewage greatly reduces the attendant expense of the process.

Among the many advantages in favor of the Separate System, the one which appeals most strongly to the average citizen is that of reduced cost. This is the argument which reaches the heart—or, what is quite as necessary, the pocket—of the taxpayer. One of the grave objections to the Combined System is its cost. The actual cost of such systems has been from $2.00 to $10.00 per foot. The cost of the Separate System has varied from 75 cents to $2.00 per foot. It is safe to say that under ordinary circumstances its cost will be from one-eighth to one-third of that of the Combined System. Mr. W. J. McAlpine estimated the cost of a Combined System for the city of Schenectady, N. Y., at $240,000. The total cost of the Separate System now completed was about $35,000.

It may be asked why the Combined System is still adopted in so many cases, if the advantages of the Separate System are so apparent. The answer to that question is, that engineering precedent carries great weight with it among engineers, and a venerable error, even, is hard to put down. The Combined

System is one of natural growth. In cities the natural water courses are covered over and converted into sewers, and branches are built leading into them. Then the branches are extended, until they form a complete system of sewers.

You can see the beginning of this system in almost any town which has a small creek running through it. The creek will be partly arched over, and branch drains will be constructed leading into it, long before the subject of sewers is brought up for consideration. When the matter does come up, the chances are that the system already begun is simply extended and completed, and another bad precedent is set, which makes the introduction of the better system more difficult.

Although local conditions and considerations of economy may in some cases make it the part of wisdom to combine storm water and house wastes in the same conduits for removal, the attainment of perfect house drainage cannot be furthered by so doing, and quite likely will be jeopardized. Nothing interfering with the utmost attainable perfection in the sanitary condition of the drains connected with the interior of our dwellings should be allowed. If sub-surface conduits for other purposes than house drainage, and not so connected, are less perfect in their sanitary condition (and from the inconstant nature of their use they must be), it is a matter of less importance; since opening into an unconfined and widely circulating atmosphere, any noxious gases are in so much greater degree diluted and rendered innocuous.

The introduction of the Separate System marks an important era in the development of sanitary drainage, recognizing, as no other system has, the prime importance of an early removal of household and industrial wastes, which are the main factors in soil pollution. That it will best meet the requirements of all large and densely populated cities (economy considered), is not probable. That, under competent advice, it can meet the requirements of *house drainage* more perfectly in *any city* than the Combined System cannot be denied. It is peculiarly adapted to many of the numerous smaller cities, which have been practically debarred from sewerage by its cost, and to outlying por-

tions of larger ones. Its comparatively small cost permits an early and general extension, and the removal of domestic wastes before the soil has become saturated with them beyond a reasonable hope of purification.

The wide application which can be made of this system will be apparent upon an examination of the following classification of the cities and towns of the United States. The table classifies all the cities and towns of the United States of 8,000 inhabitants and upward by the number of inhabitants as given in the census of 1890. The census returns also illustrate the increasing tendency toward the aggregation of population in cities where sanitary works are imperative.

"In the published records of former censuses urban population has been defined as that element living in cities, or other closely aggregated bodies of population, containing 8,000 inhabitants or more. This definition of the urban element, although a somewhat arbitrary one, is used in the present discussion of the results of the Eleventh Census in order that they may be compared directly with those of earlier censuses. The limit of 8,000 inhabitants is, however, a high one, inasmuch as most of the distinctive features of urban life are found in smaller bodies of population. Recognizing this fact, the discussion of the urban class was in 1880 extended in part to include all such bodies of population down to a limit of 4,000, a precedent which will be followed in the more extended publications of the Eleventh Census.

According to this definition the urban population of the country in 1890 was 18,235,670, the total population being 62,622,250. The urban population constituted in 1890 29.12 per cent. of the total population. Corresponding figures for the several censuses are given in the table opposite:

"It will be seen that the proportion of urban population has increased gradually during the past century from 3.35 up to 29.12 per cent., or from one-thirtieth up to nearly one-third of the total population. The increase has been quite regular from the beginning up to 1880, while from 1880 to 1890 it has made a leap from 22.57 up to 29.12 per cent., thus illustrating in a forcible manner the accelerated tendency of our population toward urban life."

TABLE I.

URBAN POPULATION OF THE UNITED STATES.

CENSUS YEARS.	Population of the United States.	Population of cities.	Inhabitants of cities in each 100 of the total population.
1790..................	3,929,214	131,472	3.35
1800..................	5,308,483	210,873	3.97
1810.......	7,239,881	356,920	4.93
1820..................	9,633,822	475,135	4.93
1830..................	12,866,020	864,509	6.72
1840..................	17,069,453	1,453,994	8.52
1850	23,191,876	2,897,586	12.49
1860...........	31,443,321	5,072,256	16.13
1870........	38,558,371	8,071,875	20.93
1880....	50,155,783	11,318,547	22.57
1890	62,622,250	18,235,670	29.12

"The following table shows the number of cities classified according to population at the date of each census:

TABLE II.

NUMBER CITIES CLASSIFIED ACCORDING TO POPULATION.

Census Years.	Total.	8,000 to 12,000.	12,000 to 20,000.	20,000 to 40,000.	40,000 to 75,000.	75,000 to 125,000.	125,000 to 250,000.	250,000 to 500,000.	500,000 to 1,000,000.	1,000,000 and above.
1790..	6	1	3	1	1	......	......	......	......	......
1800..	6	1	......	3	1	......	......	......	.....	......
1810..	11	4	2	3	......	2	......	......	......	......
1820..	13	3	4	2	2	2	......	......	......	......
1830..	26	12	7	3	1	1	2	......	......	......
1840..	44	17	11	10	1	3	1	1	......	......
1850..	85	36	20	14	7	3	3	1	1	......
1860..	141	62	34	23	12	2	5	1	2	......
1870..	226	92	63	39	14	8	3	5	2	......
1880..	286	110	76	55	21	9	7	4	3	1
1890..	443	173	105	91	35	14	14	7	1	3

According to the census of 1880 about seven-eighths of the cities of the United States (397) had less than 25,000 inhabitants. It is probable that most cities of less than 4,000 inhabitants, and many that have 8,000 inhabitants do not require a system of sub-surface removal for storm water, and that in the few remaining the system of conduits for sub-surface removal may be very limited.

It is also probable that a very small percentage of these cities of less than 8,000 inhabitants have a comprehensive plan of sewage for the removal of house wastes. The great majority of them are doubtless expending what little capital they devote

to this end, both public and private funds, in a way that will not contribute, ultimately, toward a harmonious system and consequently to a great extent wastefully.

In view of these facts and the statistics of the census bureau quoted, it becomes apparent that the separate system of sewerage must be widely extended.

CHAPTER IV.

PLANS.

In designing a system of sewers for a town, there are several things to be taken into consideration before deciding upon the plan to be adopted. The principal points to be considered are: the size of the town, its situation with reference to the disposal of sewage, the compactness of its buildings, its topography, its water supply, the character of the soil, the sanitary habits of its citizens; and its financial condition.

The amount of sewage in any town will depend upon the number of its inhabitants, their habits, and the abundance and convenience of the water supply. In a town without a public water supply the amount of sewage per head will be much less than where water is abundant. With the introduction of water works comes the multiplication of water closets, and a rapid increase in the use of water for baths and various household purposes, and the amount of sewage will rapidly increase. The volume of sewage to be provided for, in any case, may safely be taken to be equal to the volume of water used.

Sewage Disposal.—The disposal of sewage is a problem of the highest importance. When sufficient fall can be obtained the sewage is usually carried by gravity to the nearest stream, or large body of water. The effect of sewage pollution on streams and lakes is a question which is rapidly growing in importance as our population grows more dense, and more towns are sewered.

In the older countries of Europe the pollution of water courses by sewage has forced itself upon the attention of government officials, and stringent laws have been passed to protect the purity of streams. In this country the time is not far distant when the pollution of streams and lakes by sewage will

need to be forbidden by law or in many localities pure drinking water in any considerable quantities will not be obtainable.

The State of Massachusetts has already taken steps in this direction through "An act to protect the purity of inland waters." Canada has also done the same.

In many cases there is no available out-fall for the sewage, and the question of its disposal comes up at once with the inception of sewer projects.

The methods for purifying sewage by chemical processes are many and various. The object of these processes is to so purify the sewage that the water may be turned into the streams. The residuum is used as a fertilizer and for various other purposes but is practically valueless in its crude state. Wherever the right kind of land is available the sewage may be used for irrigating crops, and this has been successfully done in many cases.

Sometimes a town site is so flat that sufficient fall cannot be obtained to carry off the sewage. In this case the sewage may be pumped, or raised by Shone's System.

Storm Water.—In towns where the houses are at considerable distances apart, and no very large proportion of the surface is paved, the storm water will usually be easily disposed of without providing any underground channels for it. But in large cities compactly built, where the greater part of the surface is paved, and where the water would need to run in the streets for long distances to reach an out-fall, provision must be made for the storm water. This may be done by enlarging part of the sewers so as to carry the surface water as well as the sewage, or by constructing special conduits for the surface water. These special conduits may, in most cases be very much shorter than the sewers, as the storm water can be delivered into any natural water course within the town, while the sewage must be carried entirely out of the town. In every town there will problems arise peculiar to the circumstances in each case; and the details of the plan best adapted to any given requirements must be worked out to suit the conditions of that special case.

The Preliminary Survey.—Before any definite plans can be determined upon, a careful topographical survey must be made. A study of a reliable map of a town, with the heights of the street corners and points at changes of slope noted on it—or, better still, with the contour lines drawn on it—will enable the engineer to determine approximately what grades are available for the sewers; the best lines for the mains; and will enable him to so design the laterals as to lead the sewage by the most direct route to the out-fall.

These approximate calculations can then be tested by final computations made from the diagram in Chapter VI. If there are any defects in the assumptions of inclination made, it will become apparent from the diagram when the sizes are determined, and proper corrections can then be made.

It must not be forgotten in determining the grades to be adopted, that a continuous rise along the crown of the sewer is required for the upward passage of air-currents, as well as a continuous descent along the invert for the downward flow of sewage. To accomplish this, it is necessary when the sewers flowing into a man-hole are smaller than the outflowing sewers to which they are tributary, to raise the crowns of the former slightly above that of the latter. This frequently occasions a considerable loss of grade. For example, if a man-hole having an eighteen inch outlet has a twelve inch and a ten inch sewer tributary, and to insure a free delivery at all times we raise their crowns an inch above the crown of the outlet, the invert of the twelve inch pipe will be raised above the grade line seven inches and that of the ten inch pipe nine inches. This is illustrated in the drawing of a man-hole, Plate V. Another reason for raising the inverts of inflowing pipes at man-holes, is, that obstructions are more likely to occur at man-holes than when the sewer has its full circular section, and the increased descent thus secured tends to prevent deposits.

A preliminary survey for sewers should include such measurements as will enable the engineer to make a map of the town and profiles of the streets. The lengths and directions of the

street lines should be carefully measured, and levels should be taken at every one hundred feet and at every change of slope of the surface. A datum should be selected and its distance below some well known fixed point in the town be given. Bench marks for levels, and reference points for line should be established at every street intersection.

The establishment of bench marks should be the first step in taking the levels, and it should be done independently of the surface levels, as extreme accuracy in the final location of the grade line in construction is necessary in order that portions of the system which may be constructed separately may be properly joined. After the territory is covered with a proper system of bench marks, which have been carefully checked by cross lines and found to be correct, the surface levels can be taken very rapidly and with less care, as any error is not carried but is eliminated at the succeeding bench mark.

The transit and level notes of the preliminary survey should be carefully preserved, after they have served their purpose in the preliminary work, as they will serve as a check on the succeeding work.

From these notes a map can be made and the contour lines drawn on it (as in the maps shown in front of book), or, the height of a sufficient number of stations marked on it.

The survey should also include outlying portions of the territory which may belong to the same natural drainage basin, and for the storm water of which it may be necessary to provide special conduits. Rough profiles of the streets can now be made, and the grade lines of the sewers laid down on the profiles. The method of determining the proper grades is fully described in the following pages, as also the method of determining the loss of elevation on curves and in the case of a smaller sewer being tributary to a larger one.

Having located the out-fall of the sewers and established its height, it will be best, in determining the grades, to work from the out-fall along the mains to the laterals, as this will show the height at which each junction must be, and what fall is available.

Capacity Required.—In designing a system of sewerage, the final question to be decided, and the most important one, is the question of size.

It is obvious that proportioning a plant to meet the demands of so inconstant and widely varying a use as the removal of storm water, presents especial difficulties, both as to economy and efficiency, and that, generally speaking, the possibilities of economical construction and service are measured by the regularity of the work.

The aggregate yearly discharge of house drainage from areas fairly built up is in excess of the entire volume of storm water that ordinarily reaches the street catch-basins. Yet the capacity required for the ample service of house drainage is, approximately, but one-fortieth of that required for, or, more properly, of that usually given to, sewers for the removal of sewage in combination with storm water from streets, gullies, roofs, paved areas, etc. In fact, though representing ultimately the greater amount of work in the Combined System of sewers, it is considered unnecessary to make house drainage a factor in computations determining their sizes. (See Adams' "Sewers and Drains for Populous Districts," page 37).

It has, therefore, not been customary or necessary, in designing sewers of the Combined System, to investigate carefully the statistics of water consumption, either as to its quantity or the varying rate of flow at which it finally reaches the sewers. In designing a plant for the discharge of house sewage exclusively, a consideration of these questions becomes of prime importance.

Size is dependent not only on the *quantity* of sewage or of water consumed, which in ordinary cases is its measure, but upon the manner in which the water is used and the peculiar habits of the tributary population. A manufacturing district may consume and deliver to the sewers its entire quota, amounting to several hundred gallons per diem, per capita, within a few hours, while the sewage from a residence district may be distributed over the twenty-four hours at a nearly uniform rate.

The quantity of water actually used is but a small percentage of that wasted, and while the *use* of water in dwellings is intermittent, having ordinarily three maxima, the *waste* of water is more nearly constant, being caused by leaky and imperfect fixtures or taps purposely left open to secure fresh water or to prevent freezing.

Besides the daily variations in sewage flow, there are wide variations on different days of the week, due to the varying daily habits of the people. The maximum weekly flow is ordinarily on Monday. Thus, representing the average daily flow by 100, the maximum rate of flow during an average day may be 150, and Monday having in addition to these fluctuations those peculiar to itself, may have a maximum rate of flow one-third greater, which would be represented by 200; and since the sewers must be proportioned to discharge the maximum flow occurring at any hour during the week, in this case it should be made to carry twice the average daily flow.

Changes of Temperature.—There are also wide variations in water consumption and consequently in sewage flow, due to climatic differences and variations in temperature, which are usually too little considered in proportioning the size of sewers, and particularly of main sewers.

In a majority of our cities, the maximum consumption of water occurs during the winter months, and as it is due to water taps which are left open to prevent freezing, a greater percentage of the total consumption than in ordinary cases reaches the sewers, and the maximum rate of water consumption becomes in still greater degree the maximum rate of sewage flow. The secondary maximum of water consumption, occurring in summer, is in greater degree used for purposes which withdraw it from the sewers, as in street and lawn sprinkling, etc.

It is during this maximum rate of flow, occurring in the winter months, that sewers are more likely to be surcharged than at any other time, and it should be carefully considered in proportioning the sizes of pipes in the system. It is true that it is the result of a waste of water, which is perhaps extravagant,

and which it might be better economy to check than to remove by sewerage.

Use of Water Increasing.—It is also true that the per capita consumption and waste of water has been gradually increasing up to the present time, and is likely to reach still higher figures. This increased demand for water has been met by pumping engines of much higher duty, and by improvements in water works generally, which enable them to furnish water to the consumer at lower and lower rates per gallon, commensurate with the increased economy secured. This in turn encourages the use of water from the public mains for motive power, as the running of elevators, motors, etc., and for the thousand and one purposes of light manufacturing, requiring the use of power, always ready, and costing nothing when not wanted. The application of water under pressure as a motive power to work of this class is apparently in its infancy, and is destined within the probable life of sewerage systems now contemplated to considerably augment their flow. Rapid as has been the development of water supply systems in the United States, their capacity has barely kept up with the demands of the people.

CHAPTER V.

QUANTITY OF SEWAGE.

Owing to the scarcity and incompleteness of data at present accessible on the actual flow of sewers, and to their unreliability as well, and to the very complete records of water consumption, which are made possible by the use of pumping machinery, automatically recording its own performances, an investigation and classification of the statistics of water consumption will, undoubtedly, be of use in designing a sewerage system. Size is entirely a matter of calculation from data, mainly assumed, as:

(1) The extent of the system.

(2) The density of population, or the probable density of population in the near future.

(3) The number of gallons of sewerage per diem per capita.

(4) The varying rates of sewage discharge.

(5) The inclination of the sewers.

(6) The smoothness of the interior surfaces of the sewers.

Of the above factors entering into calculations determining size, those of extent and inclination only are capable of exact determination. And since in designing a system of sewerage for American towns, the element of future growth must be considered, not only by increased density of population, but by the extension of the suburbs, thus extending the dead ends, and practically converting what was formerly a lateral into a main, the factor of extent may be considered to have an element of uncertainty.

Upon the accuracy of the assumption made by the engineer, then, in regard to these variable factors entering so largely into his calculations, will the efficiency of the system mainly depend.

The following statistics of water consumption are given with a view of showing what may be a proper value for each of these

variable factors in ordinary cases. They have been collected from various sources, and a summary is presented in condensed tabular form, convenient for reference. A few statistics of sewage discharge are also presented, but owing to the difficulties previously stated, they indicate the condition of sewage flow for a very brief period only, and admit of but limited application. When examined in connection with the statistics of water consumption they are of increased interest.

The consumption of water will be examined in the following manner:

(1) The quantity of water consumed.
(2) Monthly variations.
(3) Daily variations.
(4) Hourly variations.
(5) Variations due to extremes of temperature.
(6) Special cases—as, cities using water largely in manufacturing, brewing, etc.

In the following tables the standard of comparison taken is the average per diem per capita consumption, which is, for purposes of comparison, assumed at 100, and from statistical data the per cent. comparison is made by computation, as this is most convenient for use.

The average per diem per capita consumption is that most readily obtained, especially from pumping records of the smaller cities in which records are usually less perfect, being computed from automatic counter readings. In many records of pumping works, where the supply is compared with the population, the results are misleading. For instance: in the smaller cities of from 10,000 to 15,000 inhabitants, while the per diem per capita consumption, based on the total population, is but little below the average, the actual per diem per capita consumption for each person using water from the city mains must be greatly above the average, as the proportionate number of consumers in such cities is frequently below one half, and, consequently, the sewage flow in proportion to the actual tributary population is disproportionately large. This condition is, undoubtedly, owing to the

usual laxity of cities of this class in controlling the use of water, and is corrected as the city increases in population and improves in its conduct of municipal affairs.

The water statistics of large cities are often misleading in the other direction, many supplying water from the city mains to their own entire population, and to outlying suburban districts as well, which, in many cases, is not stated in published reports. In many cases, also, the per capita consumption in published returns is based upon estimates of population, which are merely guesses and may be wide of the mark.

The sewerage of every city presents problems for solution essentially peculiar to itself, and these must be carefully considered. The tables here given, while not strictly applicable to certain special cases, will, nevertheless, be a guide in determining their requirements.

The Quantity of Water Required.—The following is J. T. Fanning's estimate for American cities: *

"In American cities having well arranged and maintained systems of water supply, and furnishing good, wholesome water for domestic use, and clean, soft water adapted to the uses of the arts and for mechanical purposes, the average consumption is found to be approximately as follows:

(*a*) For ordinary domestic use, not including hose use: 20 gallons per capita per day.

(*b*) For private stables, including carriage washing, when reckoned on the basis of inhabitants: 3 gallons per capita per day.

(*c*) For commercial and manufacturing purposes: 5 to 15 gallons per capita per day.

(*d*) For fountains, drinking and ornamental: 3 to 10 gallons per capita per day.

(*e*) For fire purposes: 1 to 10 gallons per capita per day.

(*f*) For private hose, sprinkling streets and yards: 10 gallons per capita per day during the four driest months of the year.

(*g*) Waste, to prevent freezing of water in service pipes and house fixtures in northern cities: 10 gallons per capita per day during the three coldest months of the year.

(*h*) Waste, by leakage of fixtures and pipes, and use for flushing purposes: from 5 gallons per capita per day, upward.

*From J. T. Fanning's Hydraulic Engineering, by permission.

"The above estimates are on the basis of the total population of municipalities.

"The domestic use is greatest in the towns and cities, and in the portions of the towns and cities having the greatest wealth and refinement, where water is appreciated as a luxury as well as a necessity, and this is true of the yard sprinkling and ornamental fountain use, and the private stable use. * * *

"The general introduction of public water works on the constant supply system, with liberal pressure in the mains and house services, throughout the American towns and cities has encouraged its liberal use in the households, so that it is believed that the *legitimate* and economical *domestic* use of water is of greater average in the American cities than in the cities of any other country, at the present time, *and its general use is steadily increasing.*"

The proportion of the above per capita per day supply naturally reaching the sewers may be summarized as follows:

(*a*)	Domestic use, - - - - - -	20 gallons.
(*b*)	Stables, - - - - - - -	3 gallons.
(*c*)	Manufacturing, - - - -	5 to 15 gallons.
(*d*)	Fountains, - - - - -	3 to 10 gallons.
(*g*)	Waste in winter, - - - -	10 gallons.
(*h*)	Flushing, - - - - -	5 to 15 gallons.
	Total supply reaching sewers,	46 to 73 gallons.

The following table illustrates the proportional increase in water consumption :

TABLE III.

SHOWING CONSUMPTION OF WATER IN TWELVE AMERICAN CITIES.

Based upon the Total Population.

CITIES.	Average Daily Supply Per Capita in Gallons.		
	1874*	1884†	1890‡
Boston	60	110	84
Brooklyn	58	63	66
Buffalo	60	151	170
Chicago	84	145	123
Cincinnati	45	76	99
Cleveland	45	88	....
Detroit	87	120	175
Jersey City	86	136	....
Louisville	24	64	62
Philadelphia	58	81	100
Washington	138	165	145
Montreal	66	88	....

* J. T. Fanning's Hydraulic Engineering.
† J. J. R. Croes' Statistical Tables, 1885.
‡ Department Reports.

The daily increasing uses to which water from city mains under a liberal pressure is put are an indication that the per capita consumption of water has not yet reached its legitimate limit.

The following table compiled from the statistics of one hundred and seventy-six American cities, illustrates the present consumption of water:

TABLE IV.

SHOWING PER DIEM PER CAPITA CONSUMPTION OF WATER IN ONE HUNDRED AND SEVENTY-SIX AMERICAN CITIES IN 1884.

Based upon the Total Population Census of 1880.*

	CITIES.	Average Consumption of water per diem per capita.
NO.	POPULATION.	
49....	10,000 to 15,000..................	76
33....	15,000 to 20,000..................	69
17....	20,000 to 25,000......	71
41....	25,000 to 50,000..................	86
11....	50,000 to 75,000.......	80
4....	75,000 to 100,000..................	95
13....	100,000 to 250,000......	102
4....	250,000 to 500,000..................	89
4....	500,000 and over	92

* Compiled from J. J. R. Croes' Statistical Tables, 1885.

The above tables, III and IV, though giving the average daily use, are not sufficient to predicate an assumption of sewage discharge upon, as they indicate simply averages obtained from widely varying rates of consumption. As previously stated, each day has a maximum rate of discharge, and there are also weekly and monthly maxima, varying according to the habits of people, and to the conditions of temperature, etc., and the sewers (we are considering the Separate System, which has no capacity of *storage*) must be proportioned to discharge their contents at the maximum *rate* at which they are received.

Varying Rates of Water Consumption.—There are two principal maxima of water consumption, one occurring

during the coldest weather, and one during the warm and dry months of late summer. It is the former which particularly influence the sewage discharge, being in most cases the maximum rate of water supply for the year, and nearly its entire volume reaching the sewer, while the uses to which water is put during the warm and dry weather maximum, diverts it largely from the sewers.

The following table indicates the monthly variations in water consumption during the year 1884, in several American cities, covering a considerable range of latitude. The computations are made from statistics appearing in official reports of the water departments of the various cities, and are reduced to the per cent. basis in terms of the average monthly consumption.

TABLE V.

ILLUSTRATING MONTHLY VARIATION IN CONSUMPTION OF WATER IN 1884, IN WHICH THE MEAN MONTHLY CONSUMPTION FOR EACH CITY IS REPRESENTED BY 100.

CITIES.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Chicago	105	107	100	102	100	98	101	102	98	95	94	96
Columbus . ..	138	100	107	83	90	93	106	112	100	91	87	95
New Orleans ..	90	77	87	90	105	106	113	109	110	113	111	96
Cincinnati.....	88	90	89	101	101	106	109	114	113	110	92	86
Wilmington....	103	79	89	83	77	125	120	114	115	106	97	90
Buffalo........	111	118	114	95	92	96	91	96	95	95	97	99
Binghampton ..	116	96	97	79	90	95	98	124	107	100	104	89

From the above table we find the average maximum monthly consumption for the seven cities to be 119 6-7, or, practically, twenty per cent. in excess of the average monthly consumption.

The daily consumption has a weekly maximum independent of atmospheric conditions, and which ordinarily occurs on Monday. The widest variations in daily consumption, however, are those due to extremes of temperature.

The relative minimum, mean and maximum daily consumption, in a few cases, is illustrated in the following table in terms of the mean daily consumption. The computations are based upon statistics contained in official reports.

TABLE VI.

ILLUSTRATING EXTREME DAILY VARIATIONS IN CONSUMPTION OF WATER IN 1884, IN WHICH MEAN DAILY CONSUMPTION IS REPRESENTED BY 100.

CITIES.	Minimum Daily Consumption.	Mean Daily Consumption.	Maximum Daily Consumption.	
				DATE.
Chicago.........	82	100	120	Jan. 23
Cincinnati.......	60	100	152	June 24
Buffalo	68	100	140	Feb. 5
Columbus	..	100	176	Jan. 1

The average maximum daily consumption in the cities, given in table VI, is 147, or forty-seven per cent. in excess of the mean daily consumption of the year.

The average maximum daily consumption, given above, indicates only averages for a period of twenty-four hours. It will be necessary to ascertain the rate of the heaviest hour's use.

Statistics showing the hourly fluctuations in water consumption are not readily accessible. A single instance is here given. The table is computed from automatic counter readings of a direct service pumping engine in Kalamazoo, Mich.

TABLE VII.

HOURLY VARIATIONS IN WATER CONSUMPTION, MONDAY, MARCH 9, 1886.

TIME.	Gallons per Hour.	TIME.	Gallons per Hour.
1 A. M.	52,528	1 P. M.	58,520
2 "	49,964	2 "	58,128
3 "	51,464	3 "	59,360
4 "	52,472	4 "	59,640
5 "	52,864	5 "	61,040
6 "	52,332	6 "	57,232
7 "	54,880	7 "	53,928
8 "	64,708	8 "	56,560
9 "	62,160	9 "	52,640
10 "	61,600	10 "	54,880
11 "	60,844	11 "	52,752
12 M.	61,964	12 "	48,328

PERCENTAGE RELATION.

Average hourly rate	100
Minimum " "	85.9
Maximum " "	115.1

If this table be examined in connection with Table X, showing sewer gaugings taken simultaneously with the counter reading, it will be particularly interesting. A graphical representation of the two on the same sheet shows almost precisely the same relative variation in each.

The following illustrations and estimates of varying consumption are taken from J. T. Fanning's Hydraulic Engineering:

"The Brooklyn diagram shows that the average draft in the month of maximum consumption was in 1872, fifteen per cent. in excess of the average annual draught; in 1873, seventeen per cent. in excess; in 1874, thirteen per cent. in excess.

"A Boston Highlands direct pumping diagram, lying before the writer, shows that the average draught at 9 o'clock in the forenoon was thirty-seven per cent. in excess of the average hourly draft for three months.

"The maximum hourly draft, indicated by the two diagrams taken together, is nearly seventy-five per cent. in excess of the average throughout the year.

"In illustration we will assume a case of a suburban town, requiring, say, an average daily consumption for the year of 1,000,000 United States gallons of water, and compute the maximum rate of draught on the basis shown by the above named diagrams, thus:

	GALLONS.
Average draught per year........................	1,000,000
Add 17 per cent. for maximum monthly average draught, making.......	1,170,000
Add to the last quantity 10 per cent. for the maximum weekly average draught, making	1,270,000
Add to the last quantity 37 per cent. for the maximum hourly average draught, making..	1,640,000
Add to the last quantity 23 per cent. for the maximum hourly average draught on Mondays, making....	1,870,000

"The maximum hourly draft is not infrequently one hundred per cent. in excess during several consecutive hours, independent of the occasional heavy draughts for fires."

Fanning's estimate, as given above, would require sewers capable of discharging twice the mean daily water consumption, upon the supposition that at the time of maximum consumption its entire volume reaches the sewers. And this being ordinarily in the winter months, the supposition is a reasonable one.

The following extracts from the report of the Louisville Water Works for 1890 shows the relation between "consumption of water per capita" and "consumption per each consumer" from 1861 to 1889.

It appears from the table that the consumption *per consumer* has been without any notable increase previous to 1880 since when there has been a considerable increase. During this period the consumption per capita based on the *total population* has increased from 8.66 gallons to 67.32 gallons.

TABLE VIII.

WATER CONSUMPTION AT LOUISVILLE, KY.

Year.	Number of Service Attachments.	Number of Premises or Houses Supplied.	Estimated Number of Water Consumers.	Estimated Population within Pipe Limits	Estimated Population in City.	Each Inhabitant per day—in Gallons.	Each Consumer per day—in Gallons.
1889	12,569	12,262	122,620	132,400	166,000	67.32	91.14
1888	11,698	11,398	113,980	131,700	165,000	62.23	77.96
1887	11,001	10,729	107,290	131,000	162,000	63.62	96.07
1886	10,243	9,990	99,900	130,500	160,000	64.95	104.02
1885	9.709	9,469	94,690	130,000	159,000	62.39	104.77
1884	9,261	9,034	90,340	125,500	158,000	56.22	98.33
1883	8,730	8,594	85,940	125,000	158,000	51.91	95.44
1882	8,293	8,201	82,010	124,500	157,000	47.11	90.19
1881	7,947	7,877	78,770	124,000	156,000	55.47	109.86
1880	7,506	7,462	74,620	123,000	156,000	42.09	88.01
1879	7,283	7,243	72,430	123,000	156,000	33.16	71.42
1878	7,012	6,978	69,780	120,000	154,000	29.35	64.77
1877	6,820	6,797	67,970	117,000	154,000	28.62	64.65
1876	6,559	6,541	65,410	116,000	152,000	27.44	63.75
1875	6,234	6,228	62,280	114,000	152,000	23.76	57.98
1874	5,431	5,591	55,910	109,000	152,000	23.68	64.37
1873	4,742	4,932	49,320	98,000	144,000	22.32	65.16
1872	4,268	4,452	44,520	84,000	136,000	21.69	66.25
1871	3,911	4,131	41,310	76,000	129,000	20.86	65.13
1870	3,436	3,668	36,680	70,000	122,000	23.09	79.53
1869	3,083	3,312	33,120	64,000	115,000	21.53	74.76
1868	2,695	3,089	30,000	62,000	109,000	18.86	66.30
1867	2,414	2,783	28,000	60,000	103,000	18.24	67.10
1866	2,205	2,434	25,000	56,000	98,000	18.87	73.96
1865	1,766	2,019	20,190	51,000	92,000	18.55	85.35
1864	1,517	1,754	17,540	49,000	87,000	14.27	62.06
1863	1,112	1,300	18,150	40,000	83,000	11.43	55.02
1862	794	925	13,000	34,000	78,000	12.98	77.91
1861	512	582	5,820	32,000	74,000	8.66	73.60

Sewer Gaugings.—Exact measurements of the flow of house sewage for any considerable period are not accessible, if they have ever been made, and, consequently we cannot use them as a basis in determining the fluctuations in sewage flow, or the ratio of maximum to mean discharge.

A limited number of gaugings have, however, been made with the purpose of determining the maximum rate of flow per capita in certain cases, and an account of some of them appears in a report to the National Board of Health, by G. E. Waring, Jr.

The most complete statistics recorded are those of gaugings made under the direction of Robert Moore, Esq., Civil Engineer, Commissioner of Sewers of St. Louis. The following is an abstract from the report:

"The sewer drains an area containing 1,370 houses, occupied by a population of 8,200. The total number of water taps was 1,390. The diagrams show gaugings taken every hour from 6 P. M. Monday, March 15 to eleven A. M., March 16, and from 8 A M., March 19, to 8 A. M., March 23. These gaugings are averaged to make a *typical* day, in which, beginning at midnight with a flow of 75.32 cubic feet per minute the flow was reduced to 70.26 cubic feet per minute at 6 A M., 130.26 cubic feet per minute at 11 A. M., 123.86 cubic feet per minute at 3 P. M., and steadily declined from this time until midnight, when the flow was 75.15 cubic feet per minute. The sewer is seven feet, three inches in diameter. It was obstructed by a dam, into which was built a twelve inch vitrified sewer pipe, which was continued for a length of twenty feet. The gaugings were taken simultaneously at three different points, the average of these being the assumed depth through the twenty feet of twelve inch pipe."

The following is a condensed tabular statement of the results obtained, as stated in the report:

TABLE IX.

SEWER GAUGINGS MADE AT ST. LOUIS.

DATA.					DEDUCTIONS.				
							Velocity in Feet per Second.		
DATE OF OBSERVATION.	Greatest Discharge in Cubic Feet per Minute.	Greatest Depth in Feet.	Least Discharge in Cubic Feet per Minute.	Least Depth in Feet.	Average Discharge in Cubic Feet per Minute.	Average Depth in Feet.	Greatest.	Least.	Average.
March 15-16	154.25	.5833	74.67	.3751	42.39	.4356	5.41	4.54	4.69
" 19	144 09	5341	77.64	3985	114.30	.4689	5.65	4.43	5.27
" 20	132.34	.5144	67.06	.3751	102.18	.4519	5.41	4.16	4.94
" 21	133.79	.5177	68.58	.3568	96.49	.4298	5.86	4.27	4.93
" 22	123.57	.4961	69.54	.3802	101.78	.4452	5.54	4.23	5.02
" 23	118.79	.4701	73.95	.3725	79.74	.3940	5.46	4.47	4.61
Typical Day, or average of March 20, 21 and 22..................					100.22	.4420	5.86	4.16	4.99

Number of houses connected with the sewer............1,370
Population 8,200
Number of water taps 1,391
Cubic feet of sewage discharged per capita in twenty-four hours.. 17.60

Upon the foregoing statistics, the following comment is made in the report:

"A computation of the amount of flow as compared with the population makes it evident that the sewer must have received a very large amount of ground water, for the total flow (over 1,000,000 gallons per day) amounted to more than 130 gallons for each member of the population, which, in a district having only about one water tap to each house, would be an impossible amount. It is usual to estimate a maximum daily use for domestic purposes of about thirty-three gallons per head of population. Deciding the total flow by this amount, we might assume that the twelve inch pipe in this instance, carrying, at its maximum, less than seven inches in depth of water, was doing the amount

of work that would be required for carrying the sewage only of a population of 30,000, supposing the sewers to be absolutely tight, so that only household wastes should enter them. This last example is, from its extent, and from the minuteness with which its details are worked out, the most important of the series. It seems to me to furnish a conclusive argument—an argument fully sustained by all of the other gaugings—in favor of the safety of depending upon very small conduits for the removal of the dry weather flow of sewage of cities and towns. It shows conclusively that the commission of the National Board of Health, which recommended the system carried out in Memphis—lateral sewers six inches in diameter, main outlet twenty inches in diameter—for a prospective population of 60,000, provided a wide margin for contingencies."

Some of the conclusions drawn above are not justified by recent experience, and do not seem to be supported by the statistics of water consumption or by other gaugings on which they are predicated.

The statistics of water consumption in St. Louis show an average per diem consumption for each tap of 1,177 gallons for the entire city. Assuming the territory tributary to the sewer in which these gaugings were taken to represent an average consumption for the city, the volume of sewage as found, 17.60 cubic feet, or 131.6 gallons per diem per capita, represents a trifle less than two-thirds the total average water consumption for the territory tributary to the sewer. The diversion of more than one-third of the total water supply from the sewers, at the season at which these gaugings were made, would in many cases, cause a public nuisance.

If the assumption of thirty-three gallons per diem per capita be properly founded on the observations made, it must be from some known local condition and not solely on the statistics as given, which are not widely at variance with similar observations made at points where it is known there can be no infiltration of sub-soil water.

The results of other investigations published in the report are not reduced to gallons per diem per capita, but, for the purpose of more readily comparing them with the gaugings made at St. Louis and elsewhere, the following table has been compiled from computations based upon the dimensions and measurements

given in the report. The results were obtained by graphical methods; but are intended to be closely approximate.

The gaugings were ordinarily taken by inserting a pipe of smaller diameter in the sewers, through which the flow was directed and in which its depth was measured. The precise manner in which these smaller pipes were placed is not stated in every case, but, as the object of the gaugings was to "determine the actual pipe capacity required" in the several cases, it seems proper to assume that they were so placed as to secure results identical with those if the entire sewer had been of an equal diameter. This is assumed in the computations made.

The gaugings of the College street sewer at Burlington, Vt., were taken at intervals of fifteen minutes from 7:30 A. M. to 10:30 A. M. The district which it drains contains eighty-five houses, of which fifty-four are connected with the sewer. The population tributary to the sewer embraces 325. There were two equal maxima in the flow, one occurring at 7:45 A. M., and the other at 9 A. M. The mean rate of discharge in this case does not represent the mean daily rate, but the mean rate during the time the gaugings were taken—7:45 A. M. to 9 A. M.

TABLE X.

COMPARISON OF SEWER GAUGINGS.

SEWER.	Length in Feet.	Diameter in Inches.	Fall per 100.	DEPTH OF FLOW IN INCHES. Minimum.	Mean.	Maximum.	POPULATION. Total.	Tributary to Sewer.	Rate of Discharge per Diem per Capita. Minimum.	Mean.	Maximum.
Report of National Board of Health.											
1880											
Compton Ave. Sewer, St. Louis, Mo., Monday and Tuesday, March 15 and 16	....	12	....	4.50	5.22	7.00	8,200	......	98	121	202
Same, Saturday, March 20	....	12	....	4.50	5.42	6.17	8,200	......	90	134	173
Same, Typical Day	....	12	...	4.44	5.30	6.25	8,200	.....	94	131	178
College St. Sewer, Burlington, Vt.	2,790	6	1.12	.80	1.04	1.20	......	325	65	115	140
Huron St. Sewer, Milwaukee, Wis.	....	10	.25	......	......	4.50	......	3,177	......	......	120
Same	....	10	.25	......	......	4.50	4,035	......	......	......	94
Other Sources.											
1881											
Main Outlet, Memphis, Tenn.	105,600	20	.166	8.50	......	14.50	35,000	......	35	.....	80
State Asylum for the Insane, Kalamazoo, Mich.	....	6	.50	......	.....	......	1,000	......	......	.....	176

The following is an account of the gaugings taken in the Memphis main sewer by C. H. Latrobe, C. E., and is quoted from his report to the Mayor and City Council of Baltimore:

"By gaugings taken at the head of the twenty-inch main I found the hourly flow of sewage to be remarkably uniform. Thus, from six A. M. till one A. M. the following morning, a period of twenty hours, the flow oscillated in centre depth from twelve and one-half to fourteen and one-half inches, the minimum area of flow being 206.5 square inches; the maximum 245.73 square inches. From one A. M. till 5 A. M., a period of four hours, the centre depth of flow varied from eight and one-half inches to eleven and one-half inches, minimum area being 107.6 square inches; maximum area, 186.9 square inches. Taking the twenty-four hours, the minimum flow is 43.7 per cent. of the maximum; taking the twenty-four hours of greatest flow, the minimum is 84 per cent. of the maximum and eight-ninths of the daily flow of sewage passed in twenty hours, one-ninth in four hours, This marked uniformity of flow during twenty hours of the day, and its oscillating character within such limits, must be somewhat influenced by the action of the flush-tanks, which probably discharge in small groups. * * * The accompanying system of tile drains has also thoroughly drained (as far as I know) the very tenacious sub-soil of the city. * * * * *

"The errors or omissions in the Memphis system are:

"First. Insufficient size in the mains to accommodate the excessive use or waste of water during severe winters, when people allow spigots to run all the time, to prevent freezing. During the winter just ended Major Humphries estimates that *one hundred gallons* per capita per day were often used, which caused the mains to run full bore and occasioned a backing up of the sewage in the lower parts of the city. This fault, of course, was not incident at all to the system, but was an oversight in proportioning the mains, and would not be felt during an ordinary winter."

Since in the case of Memphis special provision was made for the removal of the sub-soil water by separate channels, it is improbable that the flow of the sewers proper was augmented by it.

It must be borne in mind that these gaugings were made before the completion of the system at Memphis, and represent the discharge from but a limited portion of the territory upon which the per capita discharge is based, there being at that time but twenty miles of the system complete. It has since been extended to about forty miles. On the other hand, the introduction of the system into the houses was so general and prompt, that it is probable the territory sewered reached more

nearly its maximum rate of discharge within the short time intervening between its completion and the time at which the gaugings were taken than would ordinarily be the case.

The maximum rate of sewage discharge, then, as shown in Table X (eighty gallons per diem per capita), should properly be based on a much smaller population than 35,000. (The total population of the city, as given in the census of 1880, is but 33,590.) No means of determining the population occupying the territory actually tributary to this twenty miles of sewers are at hand, but it has been estimated at 20,000. Upon this basis the maximum rate of discharge of eighty gallons, as shown in the table, becomes 140 gallons.

The population actually tributary to the Compton Avenue sewer at St. Louis is not stated. If, in the case of the gaugings made in this sewer on Saturday, March 20, it be assumed that at the time of minimum flow, the entire volume discharged was sub-soil water (which is certainly not a proper assumption, since at no time during the twenty-four hours is the discharge of house sewage in a system of any extent wholly arrested), and its total amount at this assumed rate for the twenty-four hours be deducted from the discharge as shown by the gaugings, the volume of discharge remaining aggregates 43.4 gallons per diem per capita.

Again, if we assume the hourly variations of flow, as determined by the gaugings taken at Memphis, to be a proper range for St. Louis, or, in other words, assume that the ratio of minimum and maximum discharge of *house sewage* only, in the two cities is the same, we can determine the amount of sub-soil water and eliminate it. A computation made on this assumption gives us in St. Louis, for the discharge of house sewage only, when based on the total population occupying the territory, minimum, 65 gallons; mean, 102 gallons; maximum, 149 gallons per diem per capita.

The gaugings made at the Compton Avenue sewer, St. Louis, cover the entire twenty-four hours. They are illustrated graphically in the diagrams on opposite page, taken from the report.

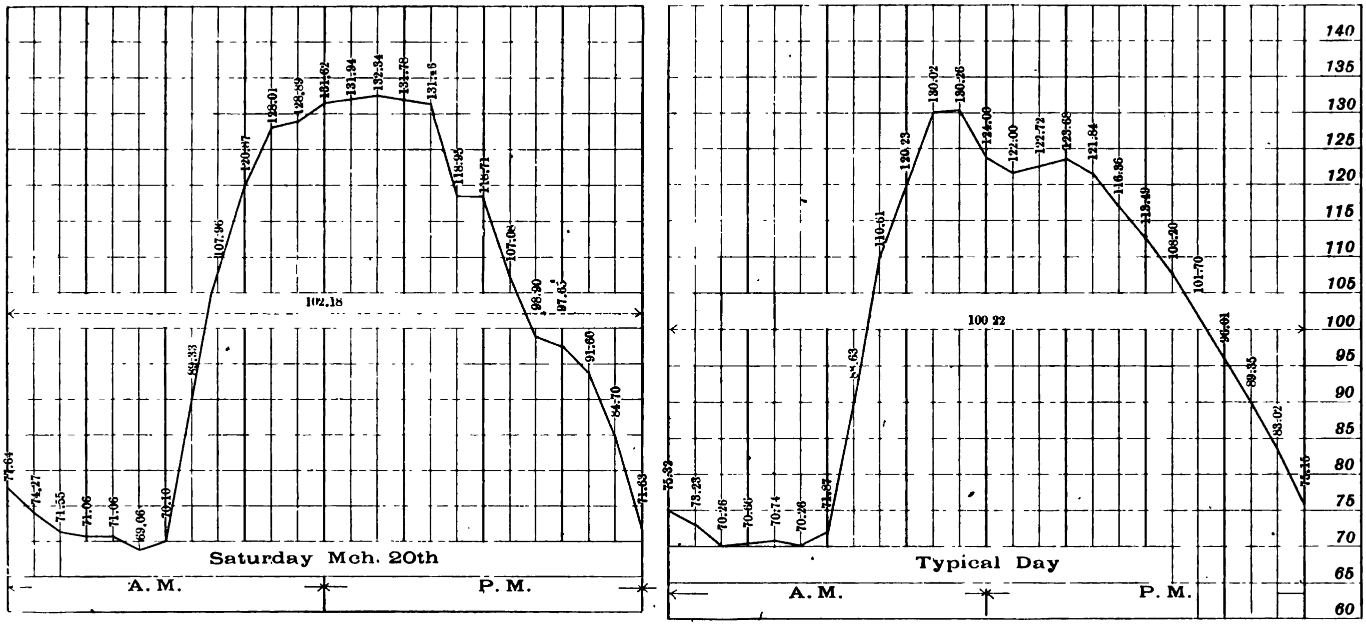


Diagram of Sewer Gaugings Made in the Compton Avenue Sewer, St. Louis.

Gaugings were made of the flow of the Water Street Main in Kalamazoo, Mich., on March 9, 1885, as follows:

TABLE XI.

DISCHARGE OF WATER STREET MAIN SEWER, KALAMAZOO, MICHIGAN, MONDAY, MARCH 9, 1885.

TIME.	Discharge in Gallons per minute.			
1 A. M.	233			
2 "	227			
3 "	224	Minimum	Average discharge per minute....................	254 Gallons.
4 "	230			
5 "	234		Maximum discharge per minute..................	287 "
6 "	242			
7 "	244		Minimum discharge per minute...	224 "
8 "	265			
9 "	255			
10 "	265			
11 "	258			
12 M.	258			
1 P. M.	255			
2 "	265		**Percentage Relation of Maximum and Minimum Discharge to Mean Discharge.**	
3 "	273			
4 "	287	Maximum		
5 "	275			
6 "	276			
7 "	265			
8 "	257		Minimum discharge...........	88
9 "	255			
10 "	255		Mean discharge	100
11 "	253			
12 "	250		Maximum discharge..........	113

These gaugings at Kalamazoo were made by weir measurement in the manner illustrated in Fig. 1.

The weir is made of galvanized sheet iron of the ordinary weight, rolled up in the form of a funnel, and riveted or lapped and soldered, its smaller end being slightly smaller in diameter than the sewer in which it is to be inserted. The larger end is

cut off at right angles to the side which is to lie in the bottom of the man-hole, and on this is fastened an end, having cut in it the notch forming the weir, as shown at *b*. The weir should stand sufficiently above the man-hole to counteract the effect of velocity of entry, and to give a free *run* to the sewage. The depth of

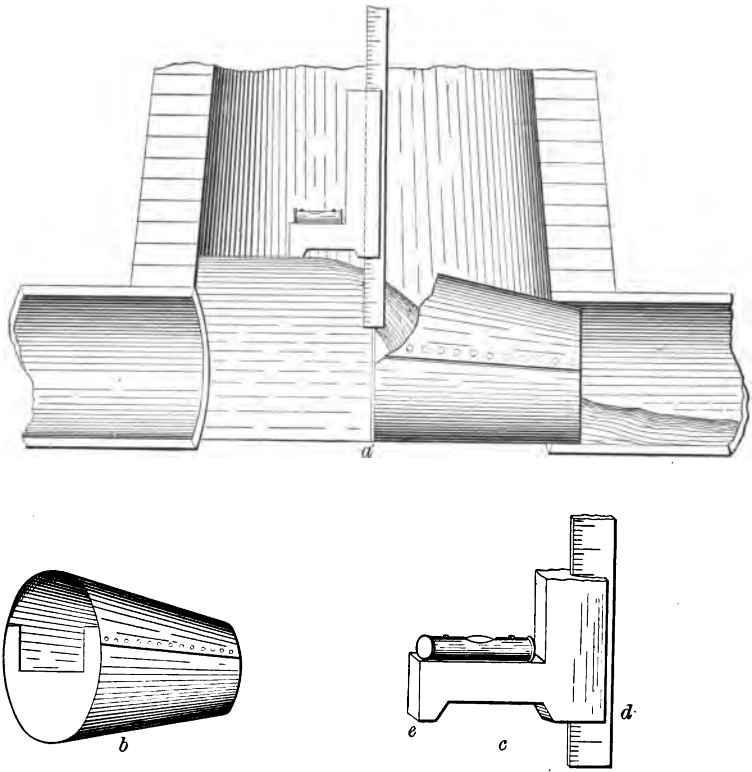


FIG. 1.

discharge over the weir is measured by a thin, graduated strip, on which travels a block having a level attached for bringing the scale into a vertical position, and the point of contact with

the surface of the water level with the index or point of reading at *d*. Still more accurate results might be had by taking the measurement from some fixed point above the weir, but in ordinary cases the method detailed above will be sufficiently accurate.

The weir is easily transferred from one point to another, and is quickly set, requiring but a piece of cloth wrapped around the lower part, when it can be crowded into the lower branch of a man-hole, where its flexibility insures a perfect fit, and the pressure of water from above keeps it to its place. It is also very convenient in use, the observation being taken from above, where the peculiar light makes the least ripple of water against the point *e*, and the position of the level bubble plainly distinguishable.

The method of observing the depth of flow in the sewer proper and computing from these data the discharge by formula or tables, though frequently used, is liable to error. The slightest obstruction below the point of observation increases the observed depth, and, consequently, gives results too high, since the diminished velocity at the point of observation is not noted. A slight increase of flatness in the grade at the point at which the observations are taken, below the grade at which the sewer may have been laid originally, has the same effect, as also the depression of a single joint or section of pipe. Opposite conditions, by increasing the velocity or by raising the measuring scale, will give results too low.

In the case of pipes of smaller diameter inserted in larger sewers, there are also difficulties in the way of securing correct results. The following gaugings, made at Milwaukee, will illustrate this point. They were made under the direction of G. E. Waring, by A. H. Scott, C. E., for the National Board of Health, and a statement of them appears in the report of 1880. They were made in this way for a particular object:

"Formulæ in use among engineers would lead us to substantially the same result with actual gaugings, but their educational effect would be less marked, because calculations based upon scientific formulæ are less readily comprehended by the average municipal ruler. * * *

"The grade of the sewer at the point where the gaugings were taken is about 1 in 400. The greatest flow in the main sewer on 'washing day'—the greatest flow of the week—attained a depth of six inches, the diameter of the sewer being forty-two inches. The channel being reduced to a diameter of ten inches, the greatest depth of flow was 4.5 inches. Reduced to a diameter of eight inches, the depth remained the same—4.5. Reduced to a diameter of six inches, it reached a depth of 5.5 inches. The influence on the velocity of the stream by increasing its hydraulic mean depth is illustrated by the following figures:

"Forty-two inch sewer, six inches deep; cross section of stream................	121.3 square inches
Ten inch sewer, 4.5 inches deep; cross section of stream....................	33.1 square inches.
Eight inch sewer, 4.5 inches deep; cross section of stream....................	27.7 square inches.
Six inch sewer, 5.5 inches deep; cross section of stream	27.14 square inches."

These figures illustrate very forcibly the superior cleansing effect of sewers discharging half full or more. They also illustrate the difficulty in securing uniform results previously cited, as shown by the following computations. The volume discharged in each case is stated as the same. The computed discharge is, approximately, as follows, leaving out of consideration the forty-two inch sewer:

Diameter.	Depth.	Discharge in Cubic Ft.
10 inches.	4.5 inches.	30.45
8 inches.	4.5 inches.	23.06
6 inches.	5.5 inches.	17.48

The inaccuracies of this manner of measuring flow become still more apparent as the depth of flow becomes less in proportion to the diameter of sewer.

From the statistics of water consumption in the preceding pages, we may conclude that the discharge of *house sewage*, at its maximum hourly flow during the year, is approximately twice the mean discharge.

The records of sewage discharge show a variation during single days covered by the observations of thirty, forty, and in the case of the Compton Avenue sewer at St. Louis, on March 15 and 16, of nearly seventy per cent. above the mean daily rate. Observations covering a longer period and varying conditions of temperature would, undoubtedly, indicate a still greater maximum rate of discharge.

CHAPTER VI.

LAWS OF FLOW IN SEWERS.

A circular sewer reaches its greatest capacity of discharge when its depth of flow is about .933 of its diameter, being at this point nearly eleven per cent. in excess of that attained when running full. When the depth of flow is half the diameter, the velocity is equal to that when the sewer is running full and not under pressure.

Circular sewers should be so proportioned as to size, throughout the system, that the depth of the ordinary daily flow will be sufficient to induce a fair velocity, and prevent deposits.

The transporting power of circular sewers of small diameter is dependent on the depth of flow in a great measure, as well as on grade and velocity. A stream having a depth of flow sufficient to immerse solid matter held in suspension, to a certain extent lifts it and carries it forward. The entire surface is also exposed to the action of the current. A stream having an equal velocity but a less depth in proportion to the diameter of the solid matters to be transported, evidently has less transporting power. As an illustration, a stream can be easily forded when its depth is below a man's waist, while the same stream in deeper water, even though the velocity be less, will carry a person down stream.

Effect of Increasing Size.—An amount of sewage which can be properly transported by a circular sewer of a given size, cannot be as efficiently transported by one of larger diameter, as the following comparison will show: If we assume the contents of a sewer of six inches in diameter, laid at a grade of .5 per hundred, and discharging half full, to be diverted to sewers of eight, ten, twelve and fifteen inches in diameter respectively, and laid at the same grade, the following depth and velocities will be attained theoretically:

TABLE XII.

ILLUSTRATING EFFECT OF INCREASED SECTION, THE VOLUME OF DISCHARGE REMAINING THE SAME.

SEWER.	Depth of Flow.	Velocity in Feet per Minute.	Discharge in Cubic Feet per Minute.
6 inch sewer.	3.00 inches.	147	14.40
8 " "	1.92 "	129	14.40
10 " "	1.36 "	112	14.40
12 " "	1.03 "	100	14.40
15 " "	.75 "	83	14.40

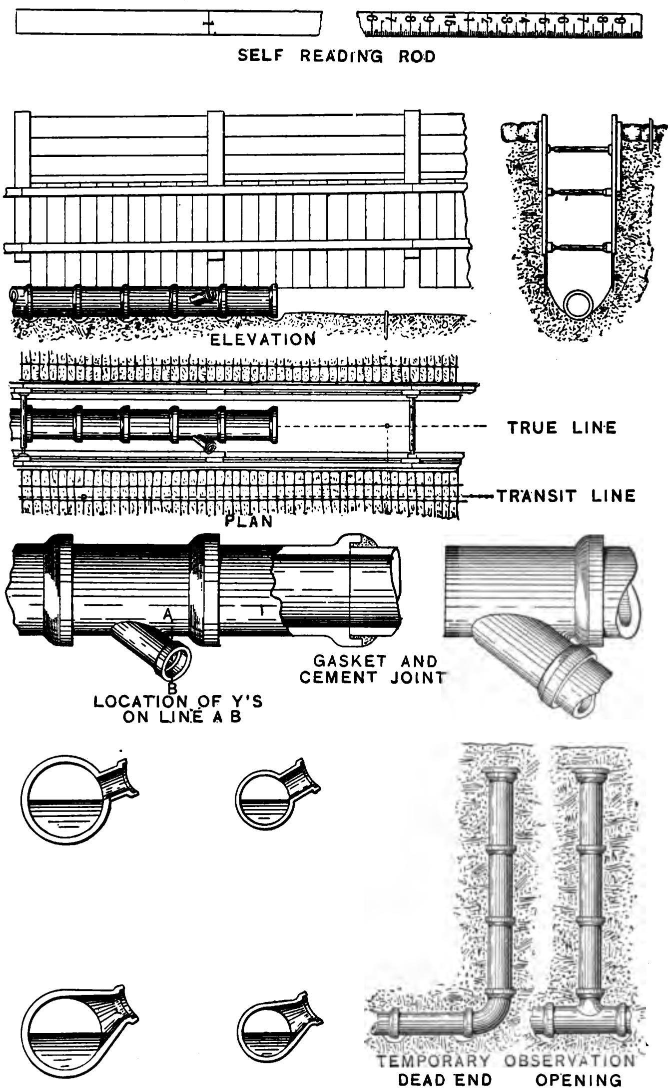
From the above comparison we see that, treated purely as a problem in hydraulics, both the velocity and depth, each of which is a factor in the transporting power of the sewer, and, consequently in a degree, a measure of its effectiveness, decrease as the size of pipe is increased. Like results have been shown practically in many cases, by the substitution of lateral sewers of smaller diameter in place of those which have not had depth of flow sufficient to be self cleansing.

It should be borne in mind, however, that while the above reasoning is entirely pertinent as applied to the treatment of a liquid that sewers are liable to be the receptacles of a certain amount of solid and refuse matter which somewhat modifies the above conclusions in some instances.

The most perfect working of the house sewers demands that they have a free out-fall into the lateral, as shown by the section in Plate I. A majority of the stoppages in house sewers occur at their entrance into the laterals and mains, and if the flow in the laterals and mains be deep enough to seal the outlet of the house sewers, the discharge of floating paper, etc., is arrested, and the difficulty at this point very much aggrivated. Good ventilation also demands a free passage of air currents through every part of the mains, laterals and house drains. The connection of the house sewer with the street sewer is ordinarily and properly made with the common Y branch, elevated, as shown by section

in Plate I. It is not made right and left hand, and when laid the sewer cannot be charged more than half bore without setting up into the house drain. The ordinary daily flow, then, for the reasons stated, and for other pertinent reasons that will appear later, should be accommodated below the horizontal diameter. An occasional extreme discharge of *short duration*, reaching the full capacity of the sewer, will be beneficial rather than otherwise.

PLATE I.


SELF READING ROD
ELEVATION
TRUE LINE
TRANSIT LINE
PLAN
A
B
LOCATION OF Y'S
ON LINE A B
GASKET AND
CEMENT JOINT
TEMPORARY
DEAD END
OBSERVATION
OPENING

Effect of Hydraulic Mean Radius.—The comparative velocity and discharge of circular sewers when running at different depths, is well illustrated by the following table:

TABLE XIII.

SHOWING THE COMPARATIVE DISCHARGE AND VELOCITY IN CIRCULAR SEWERS OF A GIVEN DIAMETER AND GRADE FOR VARIOUS DEPTHS OF FLOW.

[The depth of flow is expressed in terms of the diameter. The velocity and discharge are expressed in terms of the velocity and discharge when the sewer is running full, or when depth=1.]

Depth of Flow.	Velocity.	Discharge.
.067	.414	.0119
.100	.498	.0260
.1465	.602	.0548
.200	.6942	.0989
.250	.7698	.1497
.300	.8210	.2072
.400	.9264	.3457
.500	1.0000	.5000
.600	1.0534	.6598
.700	1.0932	.8174
.750	1.0984	.8836
.800	1.1028	.9458
.8535	1.1010	1.0009
.900	1.0918	1.0351
.933	1.0794	1.0479
1.000	1.0000	1.0000

If from the above table we construct the curves of velocity and discharge by laying off the depth of flow and the velocity and discharge as co-ordinates, the effect of the respective depths of flow upon velocity and discharge will be more apparent to the eye.

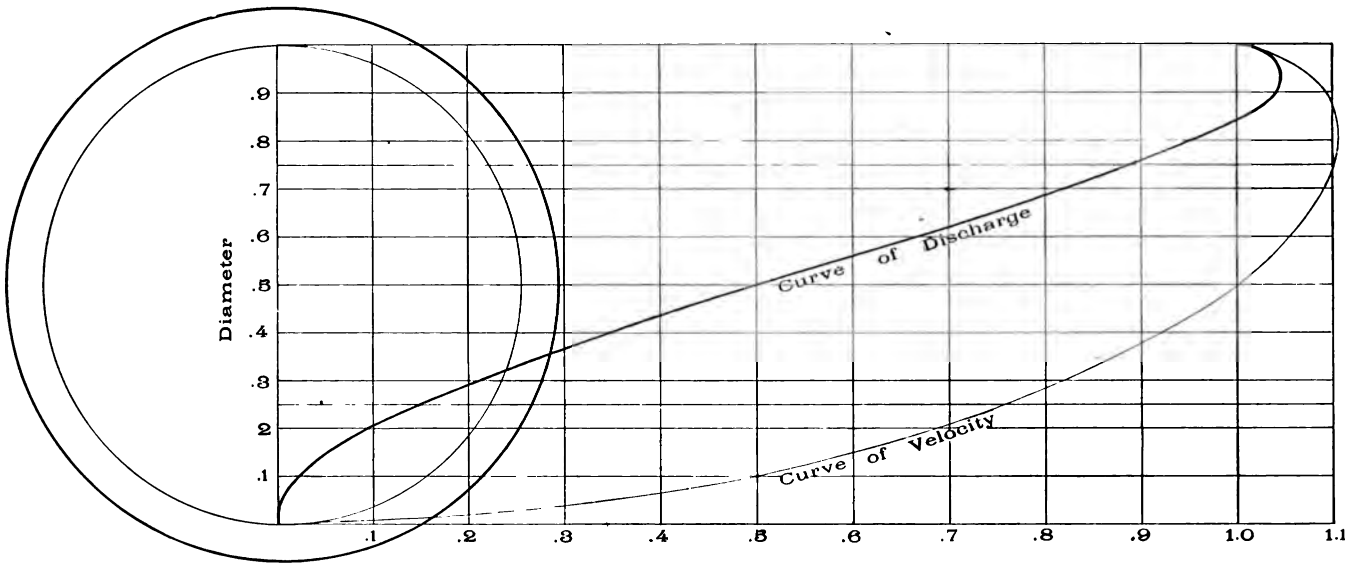


Diagram Showing Comparative Velocity and Discharge in Circular Sewers of a given Diameter and Grade, for Various Depths of Flow.

Computation of Discharge and Velocity for any Diameter and any Depth of Flow.—The diagram affords a very convenient and closely approximate method of computing the discharge of any circular sewer discharging at any depth.

Nearly all hydraulic tables bearing on this subject are computed to give the discharge of sewers running full bore. A few give the discharge when flowing one-quarter, one-third, one-half, two-thirds or three-quarters full. This is about as wide a range as can be covered without making the tables too bulky for convenience.

The discharge of a circular sewer of any size and grade, and flowing at any depth, can be determined from the diagram, as follows:

Divide the depth of flow by the diameter, and from the fractional depth on the vertical diameter thus indicated draw (by the eye) a horizontal line, intersecting the curve of discharge, and from its point of intersection a vertical to the base. The percentage thus determined on the base, will be the relation of the discharge required to the discharge of the sewer when running full, which can be taken from the table thus:

Given,

Diameter of sewer = 12 inches.
Grade = 1 in 200.
Depth of flow = 5 inches.

Required the discharge.

Solution:

$$\frac{5}{12} = .416.$$

Tracing a horizontal line from .416 on the vertical diameter to its intersection with the curve of discharge, we read from the scale below .36. The discharge is thirty-six per cent. of that if the sewer were running full. From Baldwin Latham's Tables we see discharge when running full = 167.2 cubic feet per minute. $167.2 \times .36 = 60.192$ cubic feet per minute, which is the required discharge.

The velocity of any circular sewer, flowing at any depth, can be ascertained from the diagram in the same way. The diagram has been carefully reduced to scale of one-half inch horizontal and one-fourth inch vertical, to facilitate calculations of this kind, and the fractional divisions can be read by applying an ordinary engineer's scale.

It is probable that neither the velocity or discharge of sewers, whose depth of flow is but a small percentage of their diameters, attain in practice the value theory ascribes to them, since the solid matter held in suspension in all sewage becomes partially stranded, or is not lifted clear of the invert of the sewer, and the co-efficients of resistance appearing in the formula, being applicable to a liquid only, give results too great.

Velocity Required to Prevent Deposit.—The velocity necessary to prevent deposit in sewers is variously estimated at from one to three feet per second by different authorities. Baldwin Latham states that he has found that, in order to prevent deposits in small, circular sewers, such as those of six-inch and nine-inch diameter, a velocity of not less than three feet per second should be produced. Sewers from twelve to twenty-four inches in diameter should have a velocity not less than 2¼ feet per second, and sewers of larger diameter should in no case have a less velocity than two feet per second. The minimum inclination securing these velocities in the several cases, assuming the sewers to run half full, or full, is:

6-inch pipe............	1 in 142=.704 per 100
9-inch pipe............	1 in 203=.494 per 100
12-inch pipe............	1 in 385=.260 per 100
24-inch pipe............	1 in 775=.129 per 100

The minimum velocity recommended by several authorities is as follows:

Baldwin Latham.....	2	to 3 feet per second.
Beardmore..........	2½	to 3 feet per second.
J. Phillips...........	2½	to 3 feet per second.
Rankin..............	1	to 4 feet per second.
J. W. Adams........	2½	to 3 feet per second.
Philbrick............	2½	to 3 feet per second.
Gerhard.............	2	to 3 feet per second.

While in extreme cases sewers may be laid at an inclination inducing only a velocity of two feet per second, with reasonable expectation of their serving a good purpose, it cannot be denied that they are less satisfactory in their workings, and require more care in their maintenance, especially in the upper levels of the system, where the volume of sewage is less constant.

Effect of Decreasing Quantity of Sewage.—It must be borne in mind that the flow decreases in volume in arithmetical ratio as we ascend the sewer, becoming zero at the summit. In illustration; If we assume a six-inch sewer 4,000 feet long, with a grade of .48 per 100, to have a tributary population for each 100 feet of its length of fifty persons, and each person to contribute fifty gallons per day of sewage, to be discharged in sixteen hours, with the sewer running half full, the computed maximum velocity at its lowest level, becomes approximately, 144 feet per minute. The volume of sewage, however, at distances of 250, 500, 1,000, 2,000 and 3,000 feet from its summit, is but $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ of that at the point where it is running half full, and, by computation, supposing the sewer laid at a uniform grade, the theoretical velocities at these points become, approximately, as follows:

Distance....	250 ft.	Velocity....	73.4	ft.	per min.
"	500 "	"	89.	"	"
"	1000 "	"	105.11	"	"
"	2000 "	"	124.42	"	"
"	3000 "	"	135.88	"	"
"	4000 "	"	144.	"	"

Or, assuming the inclination to be increased as we approach the summit, so that the velocity shall be maintained at the uniform rate of 144 feet per minute, the inclination at the several points, theoretically, becomes about as follows:

DISTANCE.	INCLINATION.	
250 feet.............	1 in 58.8=	1.700 per 100
500 "	1 " 85. =	1.176 " 100
1000 "	1 " 113.3=	.870 " 100
2000 "	1 " 158. =	.632 " 100
3000 "	1 " 185. =	.540 " 100
4000 "	1 " 208. =	.480 " 100

These figures very plainly illustrate what is so often observed in practice, and explain the frequency of stoppages in the higher levels of a system of sewers. They also illustrate the great benefit to be derived from the use of automatic flushing tanks at dead ends, by which the sewer is intermittently filled to a fair working capacity, and its stranded contents swept on to the mains before they have accumulated to a degree interfering with the working of the sewer. Flushing tanks at deads ends so surely counteract the defects above stated, that lateral sewers, to which they are applied may be designed with uniform inclination throughout.

The grade of streets frequently prevents the inclination of sewers being increased to the proper degree toward the summits, and in this case flush tanks are indispensible.

Minimum Velocity.—Six-inch lateral sewers laid at a grade of .4 per 100 (1 in 250) are fairly satisfactory in their workings, when supplied with automatic flushing tanks. The theoretical velocity in this case is 131 feet per minute when running half full. There is a marked difference observed, however, when the inclination is increased to .5 per 100, and the velocity to 147 feet per minute, especially during that portion of the day when the sewer is discharging below its average rate. Sewers of this diameter and grade are uniformly found in good condition when properly constructed and maintained; and, unless there is good reason to the contrary, the inclination should be sufficient to secure this velocity. The velocity in sewers of larger diameter may be somewhat less, as being ordinarily mains, their flow is more constant, and, having a greater actual depth of flow, suspended matters are wholly immersed and lose weight in a greater degree, and, consequently, are transported at a lower velocity.

Unless special means are taken to prevent deposit, the following may be taken as minimum velocities in circular pipe sewers:

TABLE XIV.

MINIMUM VELOCITIES AND GRADES IN CIRCULAR SEWERS.

Diameter of Sewer.	Velocity in Feet per Minute.	Theoretical Inclination when depth of Flow Equals One-Half the Diameter.	
		FRACTIONAL.	PER 100.
6	147.	1 in 200	.5000
8	144	1 " 280	.3571
9	142.5	1 " 320	.3125
10	141	1 " 360	.2777
12	138	1 " 450	.2222
15	134	1 " 600	.1666
18	129	1 " 760	.1315
20	126	1 " 890	.1123
24	120	1 " 1,160	.0862

Main outlet sewers lying beyond the point where houses are connected with the sewers, and which may safely work under light pressure at times, may have a lower inclination.

Where it is impossible to secure the grades above given, special precaution should be taken to keep the sewers free. Low grades have been adopted in many cases as a choice of evils, and by special precautions have been made to serve a good purpose. The following are examples:

"At Wave Crest, Rockaway, L. I., a four-inch sewer has been laid across a salt marsh for a distance of 2,800 feet. This small pipe is nearly level, the total fall being only three inches; yet, during the nine years in which it has been in use no stoppages have occurred, and no trouble of any sort has been met with. There are twenty-three houses on this line of pipe, most of which have their water-closets and one or two bath-tubs. A flush tank at the end of the line of pipe is supplied by means of a wind-mill." *Andrews in N. Y. State Board of Health.*

Undoubtedly, from the facts above given, the lower levels of this sewer work under a head, at least during portions of the time, and the velocity is measured, not by the fall divided by the length ($\frac{.25}{2800}$), but by a certain head greater than .25 divided by the length.

A main sewer in Kalamazoo, Mich., has a fall of but 1 in 1,200 for a distance of 7,400 feet. The lower 5,000 feet of this sewer is twelve inches in diameter, and the upper 2,400 feet is ten inches in diameter. The discharge is ordinarily at a rate of about 250 gallons per minute at its maximum, as taken by weir measurement. Theoretically, this should fill the twelve-inch pipe about half of its vertical diameter, and the ten-inch pipe about two-thirds of its vertical diameter. Actually the sewer is often full nearly to its crown.

This sewer has been in use four years, and there has been no serious difficulty. There is a tendency toward deposits, however, but as the sewer has few connections on this portion of its length, any tendency of this kind resulting in decreased sectional area sets the sewage back until the head thus gained induces a velocity which effectively removes all deposits.

Neither of these cases then, can be considered as warranting us in adopting these grades for a sewer which is to be tapped throughout its length by house branches, and whose crown should have air space for ventilation.

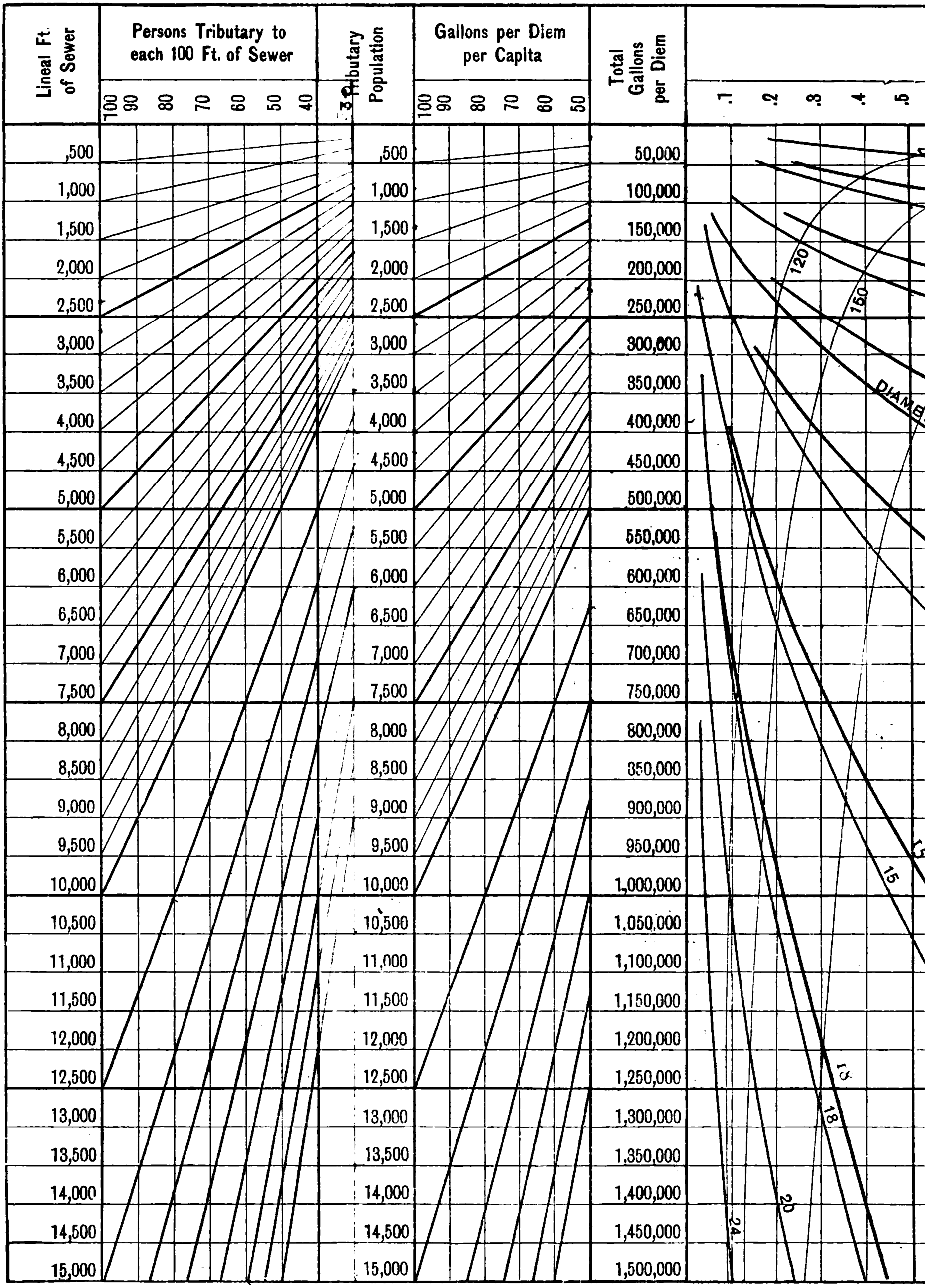
If we assume a minimum velocity of 180 feet per minute for house drains, the theoretical inclination under the above supposition (running half full) would be one in ninety-two for a four-inch sewer. A sewer of this diameter and grade, running half full, would discharge 7.85 cubic feet per minute. If we assume it to be used by a family of six persons, using 75 gallons per head per diem, the total per diem discharge becomes 450 gallons. Assuming the maximum rate of discharge at 150 per cent. of the mean rate, the maximum discharge becomes .0624 cubic feet per minute, or only eight-tenths of one per cent. of the volume necessary to secure the assumed velocity of 180 feet per minute at the grade of 1 in 92. The assumed velocity would only be reached in the case of a four inch pipe, laid at a grade of 1 in 92, as assumed above, by increasing the number of users from 6 to 750.

The actual maximum velocity obtained in the sewer when used by six persons, as above, is somewhat less than .3 its velocity when running half full, or 54 feet per minute.

GRAPHICAL SEW

BASED ON BALDWIN LATHAM'S TABLES, K

Compiled by GEO. S. PIE



WER CALCULATIONS.

S, KUTTER'S FORMULA AND ORIGINAL CALCULATIONS.

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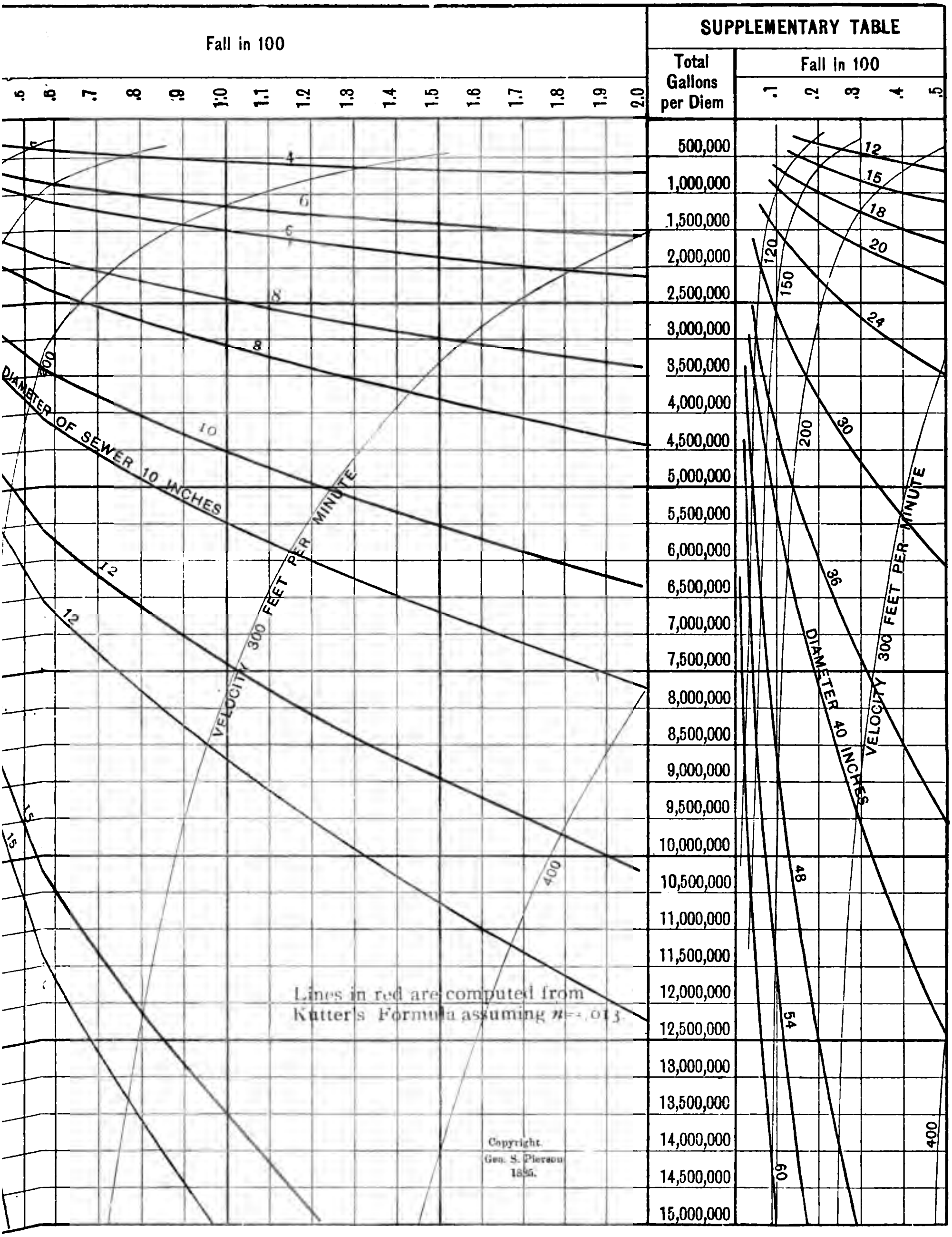

It is evident that in ordinary cases a grade of 1 in 92 in house drains will not be sufficient to prevent the stranding of solid matters. Four inch house sewers should have a grade of 1 in 60, at least, and ordinarily of 1 in 48, and unless this can be obtained special precautions should be taken against stoppage. It is evident from an inspection of Table XII that a sewer of six inches in diameter laid at the same grade, though having a greater velocity when working up to its capacity, would in this case, where the volume of flow is limited, give results inferior to a 4-inch sewer so far as the prompt removal of sewage is concerned.

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Graphical Solution.—A graphical indication of the relations of the extent of the system, tributary population, discharge, inclination and velocity, though giving but approximate results, is much more convenient in use than the most extended tables. It makes the relation of the several factors more apparent to the eye, and assists in giving the system a proper balance. It is sufficiently accurate for all ordinary computations.

A diagram showing at a glance the relation of these factors, and by which may be solved graphically and in their proper order, the problems presented will be found on opposite page.

The diagram is based upon the supposition that the depth of flow equals one-half the diameter at the time of average maximum daily flow, which is assumed at 150 per cent. of the mean daily flow for the twenty-four hours, or, a maximum rate of discharge equal to the discharge of the sewage of twenty-four hours in sixteen hours.

This relative maximum rate, though somewhat below that assumed by some authorities, will seldom be exceeded in American cities, where water is freely used, and where the waste, which is less intermittingly discharged than water legitimately used, is a large proportion of the sewage.

The following table exhibits approximately the maximum rate in several cases, expressed in terms of the time required for the discharge of twenty-four hours' sewage:

TABLE XV.

SHOWING MAXIMUM RATE OF SEWAGE FLOW.

Gaugings Taken at	Time of Discharge of Twenty-Four Hours Sewage at Maximum Rate.
St. Louis, Mo.,..	14.3 hours.
" "	18.6 "
" "	17.6 "
" "	16.4* "
Burlington, Vt.,	19.7 "
Memphis,	17.25 "
Kalamazoo,	21.2 "

*Eliminating sub-soil water upon the supposition made on page 80.

Upom the assumption previously made, that the maximum rate of discharge for the year may reach twice the mean daily discharge, the maximum rate for the year will be one-third greater than that given in the table.

The following is a comparison of the conditions of minimum, mean and maximum daily discharge, and of the maximum discharge for the year represented by 60, 100, 150 and 200 per cent. respectively, as appears consistent from the investigations made :

Discharge.	Per cent.	Depth of Flow in Terms of Diameter.	Velocity in Terms of V. when Half Full.
Minimum Daily,	60	.29	.82
Mean "	100	.39	.92
Maximum "	150	.50	1.00
Maximum Yearly,	200	.60	1.05

The total theoretical capacity becomes 300 per cent., which is equal to a margin of fifty per cent., above the greatest anticipated discharge. This would not be realized in practice, as the effect of numerous Y branches near the crown of the sewer and the flow from tributary house drains, prevent the stream from reaching its theoretical velocity.

While the margin allowed by the above supposition for extraordinary conditions is but about fifty per cent. of the greatest anticipated flow, it will, except in extreme cases, be found ample. It should not be increased without reason, as this will impair the efficiency and cleanliness of the system during the ordinary use.

The diagram is based upon the tables of Baldwin Latham and the formula of Ganguillet and Kutter. The curves in black being computed from the formula of Weisbach.

$$v=\frac{\sqrt{2gh}}{\sqrt{1+e+c\times\frac{l}{d}}} \qquad \text{(Eq. 2)}$$

in which h=head.

l=length of pipe in feet.

d=diameter of pipe in feet.

v=velocity in feet per second, when running full or half full.

c=co-efficient of friction in pipe.

e=co-efficient of resistance for entrance.

$$c=.01439+\frac{.016921}{\sqrt{v}}$$

e is assumed at an average of .505.

The coefficient of resistance for entrance (e) is not applicable to continuous, long pipes, fed at various points throughout their length. As it is usual, however, to place man-holes at intervals along the sewer, the coefficient may properly be considered.

The curves in red are computed from the formula of Ganguillet and Kutter.

$$v=\left\{\frac{41.66+\frac{1.8113}{n}+\frac{.002807}{S}}{1+\left(41.66+\frac{.002807}{S}\right)\frac{n}{\sqrt{R}}}\right\}\sqrt{RS}=C\sqrt{RS}$$

in which v=mean velocity in feet per second.

C=coefficient of mean velocity.

S=sine of slope.

R=hydraulic mean radius.

n=the degree of roughness of the sides of the conduit, determined by experiment.

In computing the diagram the value of n is taken as .013.

It is probable that this value of n though somewhat above the values of n as computed from gaugings of pipes under favorable conditions is a fair value for sewers having branches at intervals which considerably interfere with the continuity of the current.

The formula of Ganguillet and Kutter was elaborated from gaugings made in open channels.

It is, however, undoubtedly applicable to a wider range of work than any of the older formulas and is fairly satisfactory when applied to sewers of small size.

In order to properly apply the formula it is necessary to know the value of n where similar physical conditions prevail and in order to extend the usefulness of the formula as applied to sewers the following table is extracted from a larger table given in the translation of the "Flow of Water in Rivers and other Channels—Ganguillet and Kutter," by Rudolph Hering and J. C. Trautwine, Jr. From the table values of n for conditions similar to those for the work in hand can be determined.

It is to be hoped that in the near future gaugings of pipe sewers will be extended so that results may be tabulated more closely applicable to work of this class.

The following extracts from the work of Ganguillet and Kutter are given for the purpose of throwing more light upon the applicability of the formula to sewers.

"We have not yet found reason to modify our first formula. Still we must not neglect to say that it contains a variation of the coefficient C which is open to some doubt, namely, a rapid decrease of C with decrease of slope in small channels with very smooth sides. Since, however, we are not in possession of experimental data for such channels with very light slopes, we are unable to investigate as to whether our misgivings are well founded."

"The coefficient n covers not only the mere roughness of the surface, but also the irregularities and imperfections of the bed of the channel or river; it includes, further the effect of loss of head or energy, in moving detritus or silt along the bed, in shifting the main channel or current from one side to the other of the bed, and in forming eddies or other lateral and irregular currents; in short, it embodies all conditions causing retardation of flow, the relative effect of which must be left to the judgment."

It should be borne in mind, that n is to some extent dependent on the hydraulic mean radius. For the same conditions of perimeter it decreases as the hydraulic mean radius increases.

"The coefficient of resistance or roughness can be found only by consulting cases where analagous physical conditions prevail, and for which its value has already been ascertained. In doing this we must consider the effect of future contingencies upon the condition of the channel in question, such as the washing in of detritus, etc."

From an examination of diagrams by Edmund B. Weston, in Transactions of the American Society of Civil Engineers, January, 1890, comparing the coefficients of friction in pipes as computed from a large number of actual gaugings of pipes having interior sides similar to new cast iron pipes, it appears that the values of n in Kutter's formula for the pipes in question, lie mainly between the limits n=.010 and n=.012 and in the majority of cases approximately n=.011.

The value of C varies widely for different values of n as will be seen by an examination of Table XVI. It may be remarked, however, that this is precisely the feature which makes the formula applicable to such a wide range of work and that the effort to embody in a formula a variable to which can be given a value according with the condition of the channel is a step decidedly in advance.

TABLE

SHOWING THE VALUES OF *n* AS

PIPES

	AUTHORITY.	Length in Feet.
Earthenware Pipe		
Flowing partly under a slight head	Bidder, 1853	2310
Sheet Iron Rivited Pipe		
At North Bloomfield, funnel mouthpiece..	H. Smith Jr., 1876	700
New Cast Iron Pipe.	Darcy, 1851	365
		365
New Cast Iron Pipe, Sudbury Conduit.		
Coated with Asphalt..................	Stearns, 1885.....	1747

OPEN

Sudbury Conduit in Massachusetts.		
Plaster of pure cement over brick work ..	Fteley & Stearns 1880	490
Sudbury Conduit in Massachusetts.		
Hard brick, smooth surface, with mortar joints well made. Bottom slope, per thousand, about 0.16..................		600

COMPUTED FROM ACTUAL GAUGINGS.

UNDER PRESSURE.

Diameter in Feet or Greatest Depth.	Mean Hydraulic Radius in Feet R.	Hydraulic Gradient or Slope per Thousand $1000\ S$.	Mean Velocity in Feet per Second v.	Coefficient in Formula $v = C\sqrt{RS}$ C.	Coefficient of Roughness n.
1.5	.375	2.50	3.581	117.0	.0111
.911	.228	8.50	4.712	107.1	0108
"	"	13.34	6.094	110.6	.0106
"	"	16.95	6.927	111.5	.0105
"	"	25.59	8.659	113.4	.0104
.9105	"	33.09	10.021	115.5	.0102
.6168	.1542	.27	6.73	104.2	.0096
"	"	3.68	2.487	104.4	.0100
"	"	22.50	6.342	107.7	.0100
"	"	109.80	14.183	109.0	.0099
"	"	145.91	16.168	107.8	.0100
1.6404	.4101	.45	1.472	108.4	.0116
"	"	1.20	2.602	117.3	.0111
"	"	2.10	3.416	116.4	.0112
"	"	2.60	3.674	112.5	.0115
4.00	1.00	.318	2.616	146.7	.0105
"	"	.711	3.738	140.1	.0109
"	"	1.221	4.965	142.1	.0108
"	"	1.849	6.195	144.1	.0107

CHANNELS.

Diameter in Feet or Greatest Depth.	Mean Hydraulic Radius in Feet R.	Hydraulic Gradient or Slope per Thousand $1000\ S$.	Mean Velocity in Feet per Second v.	Coefficient in Formula $v = C\sqrt{RS}$ C.	Coefficient of Roughness n.
3.071	1.863	0.1606	2.529	146.2	.0114
3.575	2.048	0.1596	2.672	147.9	.0114
3.768	2.111	0.1580	2.805	153.6	.0111
.820	.577	.1596	1.149	119.7	.0110
1.041	.751	.1803	1.439	123.6	.0114
1.415	1.016	.0140	.443	117.3	.0108

Since in the general formula of Chezy

$$v = C\sqrt{RS} \qquad \text{(Eq. 1)}$$

in which v=velocity,

C=coefficient determined by experiment.

$$R = \frac{\text{area}}{\text{wetted perimeter.}}$$

$$S = \frac{\text{head}}{\text{length}} = \text{sine of slope.}$$

we have $R = \dfrac{\text{area circle}}{\text{circumference}}$ when the pipe is running full.

and $R = \dfrac{\tfrac{1}{2}\text{ area circle}}{\tfrac{1}{2}\text{ circumference}}$ when pipe is running half full.

The velocity (v) is the same when the depth of flow is one-half the diameter as when the pipes are running full.

When the depth of flow is half the diameter the discharge in cubic feet per minute becomes

$$\tfrac{1}{2}\left\{ v \times 60 \times \frac{\pi d^2}{4} \right\} = 30v\frac{\pi d^2}{4} \qquad \text{(Eq. 3)}$$

Assuming the sewage of twenty-four hours to be discharged in sixteen hours, the daily capacity in gallons of a sewer under the condition named, becomes

$$\tfrac{1}{2}\left\{ v \times 60 \times \pi\frac{d^2}{4} \right\} \times 60 \times 16 \times 7.48$$

in which v=velocity in feet per second.

d=diameter in feet;

or,

$$\tfrac{1}{2}\left\{ \frac{V}{60} \times 60 \times \pi\frac{\left(\frac{D}{12}\right)^2}{4} \right\} \times 60 \times 16 \times 7.48 \qquad \text{(Eq. 4)}$$

in which V=velocity in feet per minute.
D=diameter in inches.

The expression reduces to the following form :

$$\text{Daily capacity in gallons} = 19.5822 \times V D^2 \quad \text{(Eq. 5)}$$

If we represent the inclination and discharge graphically, by the abscissa and ordinate respectively, of a co-ordinate system, the value of the ordinate corresponding with any abscissa can be determined from the above formulæ. If we make the diameter constant, and compute for varying grades and velocities, the ordinates will determine a curve representing pipe of the assumed diameter. If we make the velocity constant, and compute for varying grades and diameters, the ordinates will determine a curve representing the assumed velocity.

In the equations of velocity and discharge, if we make D constant (the pipes running half full) the hydraulic mean radius becomes constant, and the discharge varies as the square root of the sine of the angle of inclination, or as $\sqrt{\frac{1}{100}}$, $\sqrt{\frac{2}{100}}$, etc., and the equation may be reduced to the form:

$$\text{Discharge} = \sqrt{constant \times \frac{1}{100}}, \text{ etc.}$$

The curves of diameter are, therefore, parabolas and pass through the zero of the co-ordinate system.

When the depth of flow is equal to half the diameter,

$$R = \frac{\frac{1}{2}(D^2 \times .7854}{\frac{1}{2}(D \times 3.1416} = \frac{D}{4}$$

$$v = C\sqrt{\frac{D}{4}\, s}$$

$$\text{Discharge} = 19.5822\, D^2\, C\sqrt{\frac{D}{4}\, s}$$

$$= 19.5822\, C\sqrt{\frac{D^5}{4}\, s}$$

or, the discharge varies as the square root of the fifth power of the diameter.

The use of the graphical table will best be illustrated by a few examples:

(1) *Required*, the limiting length of a sewer six inches in diameter, accommodating fifteen persons using seventy gallons each. for each 50-foot lot, the grade to be .5 per 100.

Solution. Note the point at which the curve representing diameter of sewer six inches is intersected by the perpendicular line of fall in 100=.5 From this intersection trace a line to the left, preserving the same relative distance from the parallel lines on either side, until the vertical representing seventy gallons per diem per capita is reached, then to the left and downward, preserving the same relative distance from the diverging lines on either side to the column of Tributary Population, then horizontally to the left, preserving the relative distance, as before, to the vertical representing sixty persons tributary to each 100 feet of sewer (fifteen persons for each lot fifty feet in width), then downward and to the left, preserving the same relative distance as before, to the intersection with the column of lineal feet when the distance required is read, being in this case about 2,500 feet.

Incidentally we determine that the total discharge is 105,000 gallons per day, and the total assumed population 1,500, by noting the point at which the line we traced crossed these columns in the table.

(2) *Required*, The size of outfall necessary to discharge the sewage of 12,500 lineal feet of tributary lateral sewers, allowing ten persons for each twenty-five foot lot, and seventy-five gallons per diem per capita.

Solution. Starting at the left hand column in the table at 12,500 lineal feet, follow the diagonal line upward and to the right to the vertical line of eighty persons, thence horizontally to the right across the column of Tributary Population (which is determined to be 10,000), thence diagonally upward and to the right to the vertical line of seventy-five gallons (midway between seventy and eighty), thence horizontally to the right, when

we note that the total daily discharge will be 750,000 gallons, and that it will require a sewer of the following dimensions:

20 inches in diameter........ .05 per 100 grade.
18 inches in diameter........ .11 per 100 grade.
15 inches in diameter........ .26 per 100 grade.
12 inches in diameter........ .75 per 100 grade.
10 inches in diameter........1.88 per 100 grade.

But from the curves of velocity we note that the 20-inch sewer laid at a grade of .05 per 100 has a velocity less than 120 feet per minute, which is inadmissible, and the 18-inch sewer laid at a grade of .11 per 100 has a velocity of scarcely 120 feet per minute (118 by arithmetical computation), and the minimum velocity we have assumed in Table XIV is 129 feet per minute. The conditions will be met by either of the other three sewers, and the velocity in each case will be approximately 170 feet, 240 feet and 390 feet per minute.

(3) *Required* the size of outfall sewer to accommodate a population of 100,000, using seventy gallons per diem per capita.

Solution. We observe that 15,000 is the greatest number provided for in the column of Tributary Population. At the right, however, will be found a supplementary diagram, in which the gallons are ten times the corresponding number of gallons in the main diagram. We can, therefore, use that part of the diagram to the left of the column marked "total gallons per diem" in connection with the supplementary table, by multiplying "lineal feet of sewer" or "tributary population" by 10. Starting thus at 10,000 in the column of tributary population, trace the line upward and to the right, to its intersection with the vertical representing ninety gallons, thence horizontally to the supplementary table, we read 9,000,000 gallons daily, and continuing the horizontal line we cross the sewers of

54 inches in diameter at .06 per 100 grade.
48 inches in diameter at .11 per 100 grade.
40 inches in diameter at .26 per 100 grade.
36 incher in diameter at .44 per 100 grade.

Either one of these sewers laid at the grade indicated will fill the conditions.

(4) *Required,* the number of people using seventy-five gallons per diem each, that can be served by a 4-inch house drain, laid at a grade of 2 in 100.

Solution. Tracing a line from the point where the curve of 4-inch diameter is intersected by the vertical of grade per hundred=2, to the left and horizontally to the vertical of seventy-five gallons, thence to the left and downward we read 1,000 people.

Other uses of the diagram will readily suggest themselves. Of the four quantities,

Total gallons per day,
Velocity,
Fall in 100,
Diameter,

any two being given, the other two can be determined by inspection of the diagram.

Let us take that portion of the City of Schenectady, N. Y., lying between the Erie Canal and the Mohawk River, and tributary to the Front street sub-main sewer, as an example illustrating the use of the table in proportioning a complete system. The map will be found in front of book.

The territory has at present a population of 5,000, distributed with tolerable uniformity. The aggregate length of the sewer is 15,065 feet, giving thirty-three persons for each 100 feet of sewer. In this case it is not likely that the territory will ever reach a greater density of population. We will assume, however, that it may reach a density expressed by fifty persons for each 100 feet of the sewer, and will assume a discharge of seventy-five gallons per diem per capita.

First, arrange the distance of the various branches so that the aggregate length of sewer tributary to any point can readily be seen on inspection as follows:

From corner Washington Ave. and Union St. to corner of State and Church Streets	860	
Church—Union to State	400	
	1260	
State—Church to Ferry	440	
State—Canal to Ferry	530	
	2230	2230
Ferry—State to Liberty		245
Liberty—Erie Canal to Ferry		730
		3205
Ferry—Liberty to Union		290
Washington Ave. and Union to Church	625	
Church—Front to Union	450	
	1075	
Union—Church to Ferry	425	
	1500	1500
		4995
Ferry—Union to Front		725
Washington Ave. and Front to Ferry		1200
		6920
Front—Ferry to College		935
		7855
College—Liberty to Union	350	
Union—Ferry to College	830	
College—Union to Green	665	
	1845	
Green—Ferry to College	825	
Green—R. R. to College	175	
	2845	
College—Green to Front	560	
	3405	3405
		11260
Front—College to John		420
John Street		740
		12420

Brought forward		12420
Front—John to Jefferson		255
Jefferson	600	
Madison	200	
	800	800
		13475
Front—Jefferson to Monroe		250
		13725
Monroe		500
Front—Monroe to outlet main		840
		15065

Ifwe assume the smallest laterals to be six inches in diameter and the grade to be .5 per 100, we see from the diagram that their limiting length in this case is 2,800 feet. This size will, therefore, suffice until their aggregate length exceeds 2,800 feet. Should the grade be increased, however, at this point the 6-inch sewer may be extended still farther.

Inspecting the figures made above, we determine that the size must be increased after the junction of the Liberty street and Ferry street sewers. Assuming the grade immediately below this point to be .4 per 100, we determine from the diagram that an 8-inch pipe will suffice up to an aggregate length of 5,000 feet. Inspecting the summation above, we determine that this is reached after the Ferry street sewer receives the Union street sewer and its tributary branches. From this point then, the size must be increased. Assuming the grades from this point to be .28 per 100, we determine from the diagram the limiting length of a 10-inch pipe to be 7,500 feet. From the summary of length we see that this would require a still greater increase of size, the grade being the same, 355 feet above the junction of the College street sewer. A man-hole at this point is not contemplated, and a change in size between man-holes is not advisable; we will, therefore, increase the grade, retaining the same size. Recurring to the diagram, we see that the required grade, the diameter being ten ihches and the aggregate length being 7,855 (or, in round numbers, 8,000) feet, is .32 per 100. The grade

from a point 355 feet above College street, will, therefore, be increased to .32 per 100.

Taking up, now, the branches tributary to the College street sewer, and remembering that our limiting distance for the smaller laterals is 2,800 feet, we note that the size must be increased at the junction of the Green street sewer. It is evident that from this point to the Front street main an 8-inch pipe will be ample.

Uniting the College street sub-main with the Front street main, we have an aggregate length of 11,260 feet. Assuming the grade below to be .32 per 100, the diagram gives the limiting length for a 12-inch sewer as 12,700. This is reached when we add the Madison street sewer and tributaries. From this point the grade required to reach Monroe street (13,375 feet, aggregate distance), we find by the diagram to be .36 per 100, and to reach the main outlet (15,065 feet, aggregate distance), .44 per 100, the size of sewer being maintained at twelve inches. Incidentally we note that the velocity at this point is two hnndred feet per minute, and the daily discharge 565,000 gallons.

If the formula of Kutter is preferred the procedure is precisely similar, using the red lines instead of the black ones.

The computations can be made with the same facility, commencing at the outlet and proceeding toward the dead ends. A comparison of the results obtained from the diagram by different persons show them to agree within about one per cent., an error of no consequence when the data cannot be stated with precision.

It is proper to state that Baldwin Latham, in calculating the tables on which the diagram is based, has assumed a value for *h* equal to the velocity in feet per second in each case, to simplify the computations. The tables are, therefore, strictly correct only when the length in feet equals the velocity in feet per second; multiplied by the denominator of the fractional inclination. Thus:

6-inch pipe, grade 1 in 200	490 feet.
6-inch pipe, grade 1 in 100	355 feet.
12-inch pipe, grade 1 in 400	980 feet.
12-inch pipe, grade 1 in 200	710 feet.
24-inch pipe, grade 1 in 1000	2166 feet.
24-inch pipe, grade 1 in 5000	1575 feet.

Comparison of Various Standard Formulæ.—Some authorities prefer to use other formulæ than those of Weisbach, on which the diagram is based. A comparison of the results obtained from various standard formulæ is presented below.

The following are some of the standard formulæ used by the best authorities :

Baldwin Latham, Weisbach, ... $\Bigg\}\; v=\dfrac{\sqrt{2gh}}{\sqrt{1+e+c\frac{l}{d}}}$

Kutter, ... $v=\left\{\dfrac{41.66+\dfrac{1.8113}{n}+\dfrac{.002807}{S}}{1+\left(41.66+\dfrac{.002807}{S}\right)\dfrac{n}{\sqrt{R}}}\right\}\sqrt{RS}=C\sqrt{RS}$

in which v=mean velocity in feet per second.
C=co-efficient of mean velocity.
S=sine of slope.
R=hydraulic mean radius.
n=degree of roughness, determined by experiment.

Beardmore, ... $v=100\sqrt{RS}$

Eytelwein, ... $v=93.4\sqrt{RS}$

Box, Shone, $\Bigg\}\; v=\dfrac{\left\{\dfrac{(3d)^5\times H}{L}\right\}^{\frac{1}{2}}}{373.98a}$

in which d= diameter in inches.
H=head in feet.
L=length in yards.
a=sectional area in square feet.

Darcy, ... $v=\sqrt{\dfrac{d^2H}{.00371\,(d+1)L}}$

in which d=diameter in inches.
H=head in feet.
L=length in feet.

From these formulæ the following table has been computed:

TABLE XVII.

COMPARING THE DISCHARGE IN THE VARIOUS CASES AS GIVEN BY DIFFERENT STANDARD FORMULÆ

Diameter of Sewer in Inches.	Grade per 100.	Baldwin Latham.	Kutter. n = .011	Kutter. n = .013	Kutter. n = .015	Beardmore.	Eytelwein.	Shone and Box.	Darcy.
		DISCHARGE IN CUBIC FEET.							
6	.50	28.81	25.68	21.1	16.80	29.4	27.69	27.0	30.9
6	2.00	60.17	51.36	42.2	33.60	58.8	55.38	54.2	61.8
12	.25	115.40	132.00	102.0	83.40	118.0	110.90	108.4	128.7
12	1.50	294.90	318.00	272.0	203.85	288.4	270.90	......	315.0
18	.14	236.50	294.00	234.0	191.97	243.0	229.00	223.0	264.7
18	1.00	660.90	762.00	618.0	513.00	649 0	612.00	......	718.8
24	.10	408.50	516.00	420.0	358.00	421.5	398.00	......	472.3
24	.50	958.30	1,170.00	954.0	801.00	942.6	888.00	......	1,056.0
PERCENTAGE RELATION.									
6	.50	100	89	73	68	102	96	94	107
6	2.00	100	85	70	56	98	92	90	103
12	.25	100	114	88	72	102	96	94	112
12	1.50	100	107	92	69	98	92	......	107
18	.14	100	124	99	81	103	97	94	112
18	1.00	100	115	94	79	98	93	......	109
24	.10	100	126	103	88	103	98	......	116
24	.50	100	123	100	83	98	93	......	110

It will be observed that, with the exception of Kutter's formula, the results above given, though not equal, run approximately parallel.

Kutter's formula gives much smaller values for sewers of small diameter, and much larger values for sewers of large diameter. When $n=15$, the values given by Kutter and Latham are approximately equal for a sewer five feet in diameter. This value of n, however, is not applicable to vitrified pipe sewers, well constructed, unless it be on very sharp curves, where ordinarily the work is less perfect.

Loss of Head on Curves.—An increase of inclination should be given around curves, both to overcome the increased friction due to angular change in direction, and also for the reason that, as ordinarily laid, there is a slight opening of the joints in the outward circumference and greater liability to stoppage from articles lodging crosswise.

The allowance indicated by theory for the increase of friction on curves is not sufficient, for the reason that pipes are not usually laid so truly to line or grade as when laid in straight lines, and, aside from the increased friction due to the angular change in direction, we may properly increase the coefficient of resistance to flow in the pipe.

The following is Baldwin Latham's modification of Weisbach's formula for loss of head due to angular friction:

h=head necessary to overcome angular friction.
v=velocity in feet per second.
a=angle in degrees.
r=radius of pipe.
b=radius of the bend.
$2g$=64.38.
c=coefficient.

$$h=c\times\frac{a}{90}\times\frac{v^2}{2g} \quad \text{or,}$$

$$h = \frac{c}{579.4} \times a \times v^2 \qquad \text{(Eq. 6)}$$

In which $c = .131 \times 1.847 \left\{ \frac{r}{b} \right\}^{\frac{7}{2}}$

$\frac{r}{b}$ = .1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
c = .131	.138	.158	.206	.294	.440	.661	.977	1.408	1.978

Assuming a 6-inch sewer laid with a curve of fifty feet radius, the angle of the curve being sixty degrees, or its length 52.4 feet, and the velocity above the curve to be five feet per second, the increased head necessary to overcome friction due to angular change in direction is, according to equation six, less than one-eighth of an inch. In no case which could possibly occur in curves of a proper radius will the formula give more than a small fraction of an inch as the value of h. This is too small to be considered in work of this class.

In proposing a formula for the increased head or inclination required for curves as ordinarily laid in sewer work, we may, therefore disregard the effect of angular change in direction.

If, however, we assume that the increased roughness of the pipe would increase the coefficient n, as given in Kutter's formula, from n=.011, its value as given for plaster of cement with ⅓ sand, to n=.013 and n=.015, its value as given for brick work and terra cotta pipes with imperfect joints and in bad order, we have from Kutter's formula, by computation, the following table.

TABLE XVIII.

SHOWING INCREASED FRICTIONAL HEAD REQUIRED FOR CURVES IN VARIOUS CASES.

Diameter.	Coefficient of Resistance.	Velocity.	Percentage Relation of C. *	$v=2\frac{1}{2}$ feet per second.		$v=5$ feet per second.	
				Grade per 100.	Loss of Grade per 100.	Grade per 100.	Loss of Grade per 100.
6 inch	$n=.011$	$87.35\sqrt{RS}$	100.00	.65	....	2.62	......
" "	$n=.013$	$69.77\sqrt{RS}$	79.86	1.02	.37	4.10	1.48
" "	$n=.015$	$57.15\sqrt{RS}$	66.00	1.53	.87	6.12	3.50
12 inch	$n=.011$	$105.74\sqrt{RS}$	100.00	.22	....	.89	.....
" "	$n=.013$	$84.92\sqrt{RS}$	80.31	.34	.12	1.38	..49
" "	$n=.015$	$70.8\sqrt{RS}$	66.00	.49	.27	1.99	1.10
18 inch	$n=.011$	$116.2\sqrt{RS}$	100.00	.12	....	.49	......
" "	$n=.013$	$94.7\sqrt{RS}$	81.45	.18	.06	.74	.25
" "	$n=.015$	$79.0\sqrt{RS}$	68.00	.26	.14	1.06	.57

*According to Kutter.

In the columns of loss of grade per 100 feet can be found the increased fall necessary, under the supposition that, on ordinary curves, n is increased from .011 to .013, and on sharp curves from .011 to 015.

It will be observed that when $n=.013$ the value of C is decreased to about eighty per cent. in all cases. Recurring to the general formula of Chezy, which for the ordinary range of diameter and velocity, becomes, approximately,

$$v=100\sqrt{RS}$$

We may write for ordinary curves,

$$v=80\sqrt{RS'}$$

in which $S' = \frac{h'}{l} =$ slope required.

From the preceding equations we have

$$S = \frac{v^2}{(100)^2\, R}$$

$$S' = \frac{v^2}{(80)^2\, R}$$

Or, since in each case the hydraulic mean radius when the sewer is half full $= \frac{d}{4}$

$$S' - S = \frac{v^2}{1600d} - \frac{v^2}{2500d}$$

$$H = h' - h = \frac{v^2\, l}{4444\, d} = \text{loss of head required} \qquad \text{(Eq. 7)}$$

In pipe sewers, however, the roughness is somewhat dependent on the ratio of the radius of the curve to diameter of the pipe.

Empirical Formula.—The following formula will give good results in pipe sewers:

$$H = \frac{v^2\, l}{4000d} \left\{ 1 + \frac{10d}{r} \right\} \qquad \text{(Eq. 8)}$$

in which v=velocity in feet per second.

l=length of curve in feet.

d=diameter of sewer in feet.

r=radius of axis of curve in feet.

H=loss of head for curve in feet due to increased roughness.

H in the above formula does not represent the total fall required for the curve, but the excess of fall necessary over that if the sewer were straight, and the flow had an equal velocity.

CHAPTER VII.

MATERIAL AND ACCESSORIES.

Sewer Pipes.—Salt-glazed, vitrified earthenware is the best material thus far produced for sewer pipes. It forms a smooth, impervious conduit, is not affected by the sewage, and is practically indestructible. It is manufactured in all sizes, from two inches to two feet in diameter, and in convenient forms for special purposes. The pieces are usually either two or three feet in length. They are either made with a "bell" at one end for holding the "spigot" end of the adjoining piece in laying, or as simple cylinders, with a separate collar for making the joint. The socket and spigot pipe is usually preferred. Pieces with Y branches should be placed wherever a house drain is to be connected with the sewer.

Tests of twelve-inch sewer pipe were made at Boston by Chief Engineer W. H. Bradley, with the following results:

"The pipes were three feet long and without sockets, except as noted.

"The crushing test was made by bedding the pipes, horizontally, half their depth in sand and crushing them by a weight applied uniformly along the length on the top; figures are pounds per foot of length (average of three pipes).

"The breaking test was made by supporting ends of pipes on two blocks two feet six inches apart and applying weight at center; figures are total weight (one test).

"The abrasion test was made by applying a section ½ inch square, loaded with 20 lbs., to a revolving grindstone three feet in diameter, kept wet and clean; figures are revolutions necessary, 1st, to remove glazing; 2nd, to grind away 1-10 of total thickness including glazing (average of two tests)."

TABLE XIX.

TEST OF SEWER PIPE TWELVE INCHES IN DIAMETER.

OWNERS AND KIND OF PIPE.	Weight in Lbs. per Foot.	Thickness in Inches.	Specific Gravity.	Crushing Weight, Lbs. per Foot Length.	Breaking Weight, Lbs. on 2 ft. 6 in. Span.	Abrasion.	
						Glazing.	1-10 Thickness.
Otis & Gorsline, Rochester, N. Y.	47.7	1.16	2.26	2807	4299	25	517
D. L. King, Secretary, Akron Co., Ohio	40.3	0.99	2.25	1891	3992	30	398
D. W. Lewis, Agent, Tallmage Co., Ohio	42.0	1.03	2.48	2107	4606	33	600
Hill Sewer Pipe Co., Ohio	40.5	1.00	2.32	2286	4299	25	535
T. W. Carter, Agent, Buckeye Co., Ohio	40.5	1.01	2.31	2140	4299	....	....
Wm. Nelson, Jr., N. Y. City, Scotch Pipe	43.0	1.12	2.19	1875	3982	9	32
Portland Stoneware Co., Salt Glazed	41.1	1.16	....	2495	....	14	187
" " " Slip Glazed	40.6	1.16	2.11	4652	4913	13	35
G. W. Rader, N. Y. City, Salt Glazed	40.4	1.04	....	1880	....	75	793
" " " Slip Glazed	40.0	1.10	2.17	2052	4299	12	90
Marcellus Day, Boston, Portland Cement	63.0	....	....	2316	5836	....	....
S. Richardson, Philadelphia, Carbonized Stone, 12 by 18 ¾ inches	81.1	1.00 to 1.75	2.32	2021	....	....	....

The capacity of vitrified salt-glazed sewer pipe to resist abrasion is very marked.

Hand-Holes.—A "hand-hole" is a piece of pipe provided with a detachable section. See Fig. 2. These hand-holes afford the means of removing obstructions without breaking the pipe. They are usually laid at intervals of about one hundred feet. Their use may be dispensed with and the sewer may be opened when necessary by removing the cap from a Y branch.

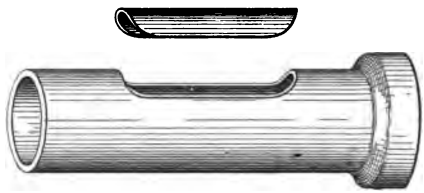


FIG. 2.

Lamp-Holes.—At intervals a T should be placed in the sewer and a stand-pipe carried to the surface, forming an opening where the action of the sewer may be observed. See Plate I. Part of them may stop just beneath the pavement and be covered with a light casting, shown in Plate I, and at longer intervals part of them may be carried to the surface and protected with a cast iron cover.

Fresh Air Inlets.—These will answer in place of manholes in some cases when the distance between the junction of two or more sewers is considerable. They afford facilities for inspection, and have the advantage of preserving the flow of sewage in its proper sectional form and precluding the possibility of deposit. They are, however, not as available as points from which cleaning tools can be inserted into the sewer. They should be covered with a perforated cast-iron cover, similar to that shown in Plate II, to assist in the ventilation of the sewer. They can be very cheaply constructed.

They should always be thus brought to the surface when it is proposed to extend a line of sewer in the near future, and can

be built up from a T or from an elbow, as shown in Plate II, and can then be used temporarily for flushing the sewer with a hose from the city hydrants.

In Plate III is shown a style of cover suitable for use in unpaved streets, where a larger chamber is needed for collecting the street detritus which works through the perforations.

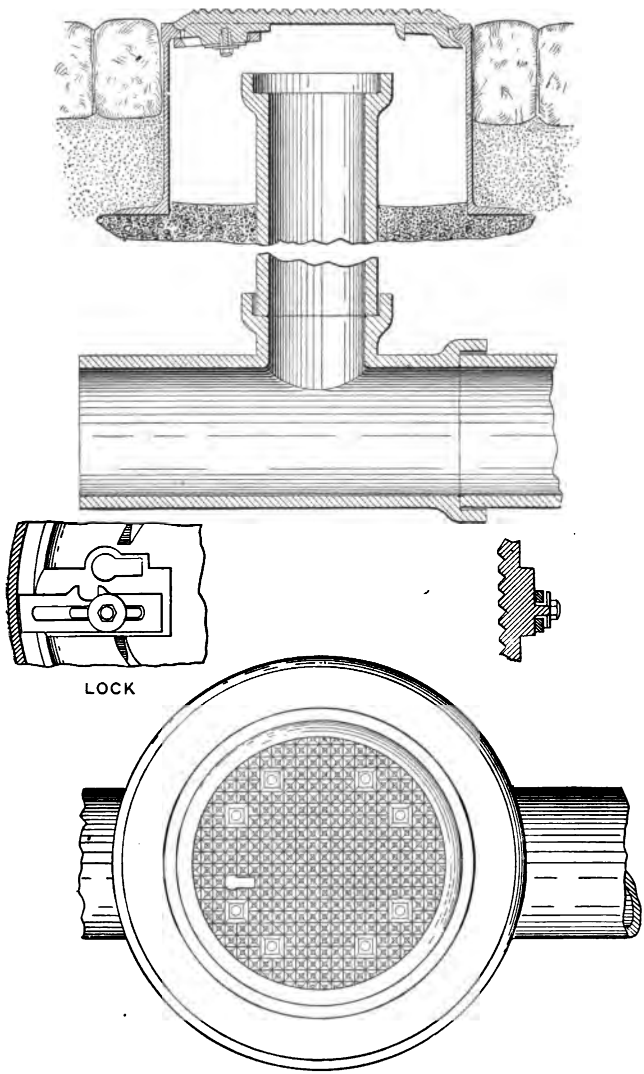
Man-Holes.—Where two or more sewers unite a man-hole should be placed. See Plates V, VI, VII, VIII. They should be built of selected, hard brick, laid in cement mortar, plastered outside, and surmounted by a heavy cast-iron cover. It is very difficult to make a proper connection between two pipe sewers of large size by the use of the ordinary Y branch. The man-holes are also required for purposes of inspection, repair, removal of obstructions and ventilation.

The advisability of omitting man-holes has been considerably discussed of late, but in cases where they have been omitted it has usually resulted in their being built subsequently. They add largely to the cost in the Separate System and should not be used more frequently than is necessary.

Flush-Tanks.—All dead ends should be supplied with automatic flushing tanks, the size of which should be proportioned to the size of the lateral. They should be built of selected, hard brick and cement mortar, and plastered inside and outside, and surmounted by a heavy iron cover. They are usually supplied with water from the street mains through an ordinary service pipe of small size, and the admission of water is controlled by an ordinary lever handle stop-cock. They are built in various forms and will be more particularly described in the chapter on Flushing and Ventilation.

Y Branches.—The usual form of Y branch is shown in Plates I and X. It consists, essentially, of a cylinder of smaller diameter intersecting the main pipe at an angle of about thirty degrees, measured on the side of the intersection toward the socket end of the main pipe. The axis of the intersecting cylinders meet in a common point. The Y branch can, therefore, be turned to the right or left with equal facility.

PLATE II.

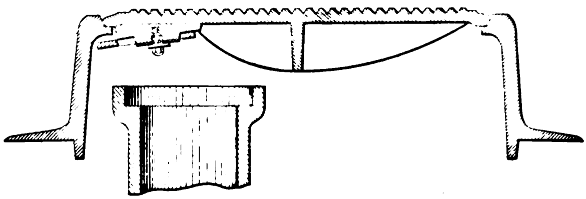


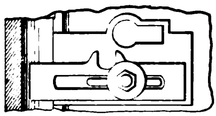
DETAILS

—OF—

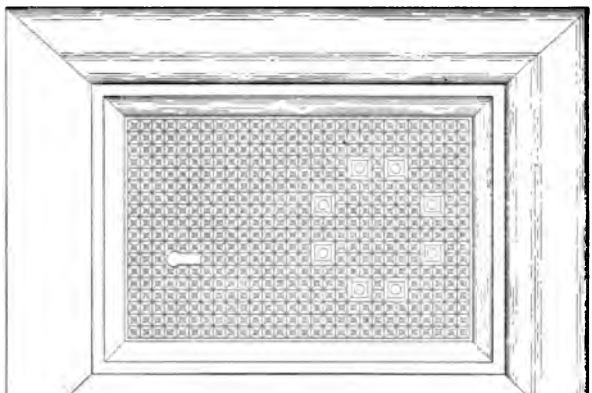
FRESH AIR INLET.

PLATE III.





LOCK



DETAILS

—OF—

FRESH AIR INLET.

Another form of Y branch is shown in section in Plate I. It consists of an intersecting frustum of a cone, the diameter of whose base is equal to the diameter of the main pipe and common with it. It is claimed for this branch that it induces a more perfect ventilation by entirely withdrawing the air from the crown of the main sewer.

It is open to the objection that it does not preserve the proper cross-sectional form of the stream but allows it to spread out laterally into the branch itself, thus breaking up the continuity of the flow, decreasing the velocity, and tending to the formation of eddies and deposits.

The comparative effect of the two styles of Y branch upon the cross section of the stream when the pipes are flowing half full is shown in Plate I.

CHAPTER VIII.

SPECIFICATIONS AND CONTRACT.

Letting the Contract.—Having determined upon the plan for a system of sewers, the sizes of the pipes required for the different lines, and the details of the accessories, the next step is to arrange for constructing the sewers.

The usual way is to advertise for bids for constructing the work according to the plans and specifications prepared by the engineer. A description of the work and approximate quantities —subject to change by the engineer—may be given either in the notice to contractors, or in an estimate filed with the detailed plans and profiles, which have been prepared to accompany the specifications. All drawings should be carefully made to scale, and full descriptions of them should be written out, so that every point may be made plain and nothing left to be inferred.

As a guide in this work a few blank forms are presented, which can be modified to suit the requirements of particular cases. They have all been tested in actual work.

[FORM FOR ADVERTISEMENT.]

NOTICE TO CONTRACTORS.

Sealed proposals will be received at the office of the Sewer..............
......................, in the City of..................................
until..... o'clock.........., on the...........day of.... ...., 189..,
for constructing sewers in..
....

Forms of proposals, copies of the specifications, and instructions to contractors may be obtained of the Engineer; and the plans and profiles may be seen at his office.

Each bid must be accompanied by a deposit of \$.......... as a guarantee of the good faith of the bidder.

The Committee reserve the right to reject any or all bids.

Address,

....

....

....

Engineer.

[INSTRUCTIONS TO CONTRACTORS.]

TO CONTRACTORS.

1. All bids must be made upon the printed forms, to be obtained at the office of the Engineer, and enclosed in a sealed envelope, directed to the Engineer of Sewers, ... and endorsed upon the outside of the envelope, *Proposal for Constructing Sewers in the City of*...

2. Each bid must be accompanied by a deposit of............Dollars, to be left in the hands of the City Clerk, subject to the conditions specified in the proposal hereto annexed, as a guarantee of the good faith of the bidder.

3. Bids shall state the price per lineal foot of pipes of each size laid as herein specified, and for the various depths of trench named, also for all other items enumerated in the schedule opposite, which price shall be in full for all labor and materials required for the complete execution of the work.

4. All prices must be written in words, and also stated in figures.

5. The place of residence of each bidder must be given after his signature, which must be written in full. When firms bid, the individual names of the members shall be signed in full, and the firm name added.

6. The name of the contractor must be filled in the blanks left for that purpose.

7. The City of......................................reserves the right to reject any or all bids.

8. Bidders are requested to be present at the opening of the bids.

9. The bond required of the successful bidder shall be in the sum of \$............

[FORM OF PROPOSAL.]

PROPOSAL.

To the Mayor and Common Council of the City of................ ....

GENTLEMEN: The undersigned hereby propose to furnish all of the materials and do all of the work required to complete such amount of the above mentioned work as shall be awarded to the undersigned by the City of ....in a first-class manner, and in accordance with the specifications hereto annexed, and the plans and drawings of the same on file in your Engineer's office, at the following prices, viz.:

ITEMS.	Price in Figures.	Price in Words.
Price per lineal foot for furnishing and laying 18-inch pipe, including Ys, branches, detachable covers, and cement joints		
Price per lineal foot for furnishing and laying 15-inch pipe, including Ys, branches, detachable covers, and cement joints		
Price Per lineal foot for furnishing and laying 12-inch pipe, including Ys, branches, detachable covers, and cement joints		
Price per lineal foot for furnishing and laying 10-inch pipe. including Ys, branches, detachable covers, and cement joints.		
Price per lineal foot for furnishing and laying 8-inch pipe, including Ys, branches, detachable covers, and cement joints		
Price per lineal foot for furnishing and laying 6-inch pipe, including Ys, branches, detachable covers, and cement joints		
Price per lineal foot for all excavation and back-filling under 6 feet deep		
Price per lineal foot for all excavation and back-filling 6 feet or over, and under 8 feet		
Price per lineal foot for all excavation and back-filling 8 feet or over, and under 10 feet		
Price per lineal foot for all excavation and back-filling 10 feet or over, and under 12 feet		
Price per lineal foot for all excavation and back-filling 12 feet or over, and under 14 feet		
Price per lineal foot for all excavation and back-filling 14 feet or over, and under 16 feet		
Price per lineal foot for all excavation and back-filling 16 feet or over and under 18 feet		
Rock Trench per lineal foot, per foot in depth		
Price per lineal foot for repaving		
Man-holes, complete, each		
Lamp-holes, " "		
Flush-Tanks, " "		
Price per ton for iron pipe, laid with lead joints, complete		
3-inch drain tile, laid, per foot		
4-inch " " "		
5-inch " " "		

6-inch drain tile, laid, per foot........................	....	....
42-inch brick sewer, laid, per foot.....................	....	....
40-inch " " "	....	....
36-inch " " "	....	....
30-inch " " "	....	....
24-inch " " "	....	....
Embankment, price per cubic yard..................	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....

And......hereby agree to enter into a contract within five days from the date of your acceptance of this proposal, to finish and complete said work (by the... ......day of,.......... ....), according to the form hereto attached, and the plans and specifications on file in the office of the Engineer, under which the bid was made, and will furnish such sureties for the faithful performance of such contract, the payment for materials contracted for, and for the payment of laborers' wages and liens which may arise therefrom, as shall be approved by the City Council.

In default of the performance of any of the conditions on........part to be performed, the sum of .... .Dollars, which............ have this day deposited with the City Clerk, shall, at the option of the said City Council, be absolutely forfeited to the City of........................; but otherwise said sum of........................Dollars shall be returned to............

Dated at........................ ...., the................day of ...., 189..

[Contractors Signature,] ....

....

....

....

....

[P. O. Address,]....... ....

No............ [State,]..................

[FORM FOR RECEIPT.]

$.......... ....189..

RECEIVED of...,
City Clerk of the City of...
....Dollars, being the amount
deposited with the above proposal.
No........... ....

[FORM FOR RECEIPT.]

$........... ....189..

RECEIVED of...,
on behalf of the City of..
the sum of..... ....Dollars, subject to the
conditions named in.............proposal to the Mayor and Common Council
for...
...........................of even date herewith, which sum, if the same
shall not be declared forfeited by said Common Council, will be returned to
said.., upon the
surrender of this receipt.
No............ ....

City Clerk.

[FORM FOR SPECIFICATIONS AND CONTRACT.]

ARTICLES OF AGREEMENT.

Between the City of.......................................
party of the first part, and ....,
Contractor, party of the second part, for building.........................
........................*Sewers in*................... ....
....

THIS AGREEMENT, made and entered into this.... ....day of
.........................., in the year one thousand eight hundred and
................., by and between the City of,.........................
party of the first part, and...,
Contractor.., party of the second part.

Witnesseth, Whereas, The City of........... ...., in the State of......................, by virtue of the authority vested in the Common Council by the Legislature of the State of............... ...., and by the Charter and Ordinances of the City, agree to let unto the said ...., Contractor.. the work of constructing certain........................Sewers, as per plans and profiles of the work on file in the office of the Engineer of Sewers.

Now, Therefore, in consideration of the payments and covenants hereinafter mentioned to be made and performed by said party of the first part, the said.................................hereby covenants and agrees to do the work above mentioned in a substantial and workmanlike manner, in conformity with the plans, profiles and specifications of such work on file in the office of the Engineer, in strict obedience to the directions which may from time to time be given by the said Engineer or his duly authorized assistants, and in accordance with the following specifications :

SPECIFICATIONS FOR SEWERS.

In the City of......... ....

BRICK SEWERS.

1. The ground shall be excavated in open trenches to the necessary width and depth. The trenches shall be opened at least one foot wider on each side than the exterior diameter of the sewer intended to be laid. The bottom of the trenches shall be formed to the required grade and to the shape of the sewer, so that the whole surface of the under half of the sewer shall have an even bearing throughout. In the trench thus formed shall be spread cement mortar, as the bricks are laid, not less than one inch thick; upon this shall be laid the inverted arch. The upper half of the sewer shall be covered with a coating of cement mortar not less than ¼ inch thick. The work shall be backed in, carefully ramming and packing under and around the sewer with proper tools, by a trusty person approved by the Engineer.

2. In the construction of the work, none but the best quality of whole brick, burnt hard entirely through, shall be used. They shall be thoroughly wet immediately before being laid. Every brick is required to have full cement joints on the bed, sides and ends, unless otherwise ordered by the Engineer, which for each brick is to be formed at one operation, and in no case is to be made by working in the cement after the brick is laid; not more than two courses of bricks shall be laid without being lined. The bricks in each course shall be laid as stretchers and shall break joints with those of adjoining courses. The bricks shall be culled before being brought upon the ground, and all brick of an improper quality, and all bats, removed from the street.

3. The cement mortar shall be composed of the best quality of fresh ground ....cement, mixed in the proper proportion of one part of cement to two parts of clean sharp sand, free from loam and shall be used immediately after it has been mixed; any that has stiffened by commencing to set shall be rejected. All cement will be subject to inspection and test before it is used, the Engineer to decide upon the character and severity of the test, and if found of improper quality it must be immediately removed from the work.

4. Whenever it shall be deemed necessary by the Engineer, the sewer shall be built in a wooden invert constructed of 1½ inch pine plank, securely nailed to 2x3½ inch ribs placed not more than 6 feet apart and formed to correspond with the exterior of the sewer, which invert shall extend each side of the sewer at least one-third the height of the same.

5. The sewer shall conform in shape and size to the pattern furnished by the contractor, and made from drawings furnished by the engineer.

6. The whole of the joints of the inner face of the sewer, below the springing line of the arch, to be smoothly and properly struck. Those above the springing line, scraped even with the bricks as soon as the centres are struck. The refuse mortar must be immediately removed from the sewer.

7. In keying the crown of the arch no headers are to be used. The inner and outer courses of stretchers are to be carried over and keyed separately, and each course in the crown of the arch is to be thoroughly grouted with grout composed of equal parts of clean, sharp sand, and best quality of fresh ground .... cement, as directed by the Engineer.

8. All brick work must be racked back in courses, and when new work is to be joined to it, the surface of the bricks must be cleaned and moistened. The inner ring shall be laid of selected brick. No inside joint shall be greater than 3-16 inch.

9. The upper arch shall be laid upon centres, not less than 10 feet long for straight work. For curved brick sewers, the centres must correspond with the radius of the curve. The centres shall not be drawn until the back filling is above the top of the arch, without the permission of the Engineer. All centres and templets shall be scraped clean before use.

The contractor will be held responsible for any distortion of the sewer by reason of the subsequent settlement of the trenches.

10. Man-holes shall be built into the sewer at such places as the Engineer may direct; the side walls to begin at the springing line of the upper arch of the sewer. Size, form, thickness of wall, cover and all details to conform to the Engineer's drawings accompanying the specifications. wrought iron steps of 7-8 inch round iron shall be placed in the man-holes. Distance apart of

steps, 18 inches; length of tread, 10 inches; projection from brick work, 4 inches. The iron to extend through the wall and clinch one inch on the outside.

11. Branch sewer connections and house connections shall be built into the sewer at such points and in such manner as the Engineer may direct. Branches not to exceed on an average, one every 25 feet on each side.

EARTHENWARE PIPE SEWERS.

12. The sewers shall be constructed of first quality vitrified, salt-glazed sewer pipe, sound and well burned throughout their thickness, impervious to moisture, of smooth and well glazed exterior and interior surfaces, free from cracks, flaws, blisters, fire-checks, and all other imperfections, circular in the bore, of true form in their lengths, whether straight or curved, internally of the exact specified diameter, and of uniform standard thickness.

13. All pipe shall be socket pipe, with true and circular sockets concentric with the bore of the pipe, and shall be furnished in pieces two feet long. For all junction pieces, a well fitted vitrified stopper shall be furnished, without charge.

14. A Y branch connection of......inches, in diameter, shall be provided every 25 feet, on each side, when ordered by the Engineer.

IRON PIPE.

15. Iron pipe shall be used where the sewer runs under or through waterways—either natural or artificial—or under a railroad, or wherever it is deemed necessary by the Engineer. The joints shall be of lead, properly caulked. The lengths of pipe, their diameter and thickness to be as directed by the Engineer. The weight of each pipe shall be plainly marked on it before leaving the factory.

16. The iron pipe shall be paid for by the ton, laid in place with joints complete.

LOCATION.

17. The sewers shall be located on the lines shown on the plans of the work, and will be staked out by the Engineer. This line, whenever practicable, will be on the centre line of the street. The Commissioners, however, reserve the right to move the line of sewers to the right or left whenever obstructions are met which render a change of line desirable.

18. The contractor will be required to preserve all stakes and bench marks until permission is given by the Engineer to remove them.

19. The line for trenches will be indicated by stakes set at one side of the trench. A width of at least two feet, on the side of the trench where the stakes are, shall, as the work progresses be kept free from obstruction.

EXCAVATION.

20. All excavations shall be by open cut from the surface. No tunneling will be allowed, except written permission be previously obtained from the Engineer.

21. The contractor will be required to keep the sides of the excavation vertical, by bracing or otherwise; but no allowance will be made therefor unless the same is left in the trench by written order of the Engineer.

22. The excavation, at the bottom, is to be made and shaped as nearly as possible to fit the lower half of the pipe to be laid, with holes cut at the joints for the sockets to rest in, so that the pipe shall have a uniform bearing on the ground from end to end.

23. At the height of half of the diameter of the pipe from the bottom, that is, at the height of the greatest horizontal diameter of the pipe, all trenches are to be eighteen inches wider than the greatest diameter of the pipe to be laid therein.

24. The trench shall be dug to within six inches of grade by measurement from the witness stakes on the surface. The last six inches shall be taken out after the grade pegs have been set in the bottom of the trench by the contractor under the direction of the Engineer.

25. The excavations for all man-holes, flush tanks, and other accessories shall be sufficient to leave at least one foot in the clear between their outer surfaces and the embankment or timber which may be used to protect it.

26. The approximate depth of the cutting will be given by the Engineer before the excavation is begun. Grade and line will be given by the Engineer every 25 feet at the bottom of the trench, on stakes to be furnished and set by the contractor; or on overhead pieces, from which the position of the invert may be determined by a line parallel therewith.

27. In no case, without previous written permission from the Engineer, shall more than 500 feet of trench be opened in advance of the completed sewer and on the completion of each 500 feet of sewer, the street surface must be restored in good condition and all surplus material and rubbish from that section be immediately removed.

28. The material excavated shall be laid compactly on the sides of the trench and kept trimmed up so as to be of as little inconvenience as possible to the traveling public and adjoining tenants.

29. The contractor shall not obstruct the gutter of any street, but shall use all proper measures to provide for the free passage of surface water along the gutters.

30. The contractor shall provide for all water courses and drains interrupted during the progress of the work, and replace them in as good condition as he found them. The use of any portion of the sewers shall not be constructed as an acceptance of them by the Commissioners.

31. No additional compensation shall be allowed, for excavating manholes, or flush tanks over the price per lineal foot for trench.

32. The contractor shall keep the trenches free from water during the progress of the work, as no pipe of masonry shall be laid in the water.

PROTECTION OF PROPERTY.

33. The contractor shall, at his own expense, shore up, protect, and make good, as may be necessary, all buildings, walls, fences or other property injured, or liable to be injured during tha progress of the work; and the contractor will be held responsible for all damage which may happen to neighboring property from neglect of this precaution, or from any other cause connected with the prosecution of the work.

PROTECTION OF WATER AND GAS-PIPES, ETC.

34. The contractor shall do whatever may be necessary to keep in position and to protect from injury all water and gas pipes, lamp posts, service pipes, and all other fixtures which may be met with in carrying on the work.

35. In case any of the said gas or water pipes or other fixtures be damaged, they may be repaired by the parties having control of the same, and the expense of such repairs shall be deducted from the amounts which may become due the contractor.

PROTECTION AGAINST ACCIDENTS.

36. The contractor shall erect suitable barriers around all excavations, to prevent accidents to passengers on the streets, and shall place and maintain during the night sufficient red lights on or near the work.

37. The contractor shall have charge of, and be responsible for, the entire line of sewers for whose construction he has contracted, until their completion and acceptance. He shall also be liable for any defects which may appear in his work before the final payments specified herein.

BACK-FILLING.

38. The earth filled around and on top of the sewers shall be free from stones, and tamped with the utmost care, so as to obtain the greatest compactness and solidity possible. In filling, the earth shall be kept at the same height

on both sides of the sewer when required by the Engineer. The earth shall be rammed in layers of not more than one foot thick up to the surface of the street, and in no case shall the number of men filling be more than twice the number of men ramming In lieu of ramming, the earth may be thoroughly puddled.

39. The contractor is required not to sell, remove or permit to be removed from the line of the work, before the trench shall have been refilled, any sand, gravel, or earth excavated therefrom which may be suitable and required for refilling.

40. The trench must in all cases be filled to the proper grade with suitable material. Should there be a deficiency of proper material for refilling the trench, the contractor will be required to furnish the same at his own cost.

REPAVING AND RESTORING STREETS.

41. When the pavement has been removed, it must be replaced by the contractor and left in as good condition as it was before being removed.

42. As the trenches are filled in and the work completed, the contractor shall remove all surplus material, without additional compensation, to localities not interfering with the regulaticns of the city, and shall leave all roads and places free, clean and in good order.

43. All work of restoring the surface of the streets shall be done to the satisfaction of the superintendent of streets.

44. If at any time during a period of one year from the date of the final completion and acceptance of the sewer, the roadway on the line of the sewer shall require regrading, repaving or regraveling, by reason of the settlement of the trenches, the Commissioners shall notify the party of the second part to make the repairs so required; and if the party of the second part shall neglect for a period of ten days to make such repairs to the satisfaction cf the Commissioners, then the Commissioners shall have the right to cause the repairs to be made, and to pay the expense thereof out of the sum retained for that purpose.

EMBANKMENT.

45. Where embankment is necessary to support the foundations of the sewer, or to cover or protect it in any way, it shall be made of the width and slopes as shown on the plan. The surface of the ground receiving the embankment shall be carefully cleared of all muck or unsuitable material, of whatever nature.

The embankment shall then be formed of good loam or gravel, free from all stones over four inches in diameter, and of those below that size in a proportion not exceeding one part of stone to three parts of earth in any place.

If built to support the foundation of the sewer, the material is to be deposited in layers of not more than six inches in thickness, each layer to be separately compacted by heavy iron rollers, or, where these cannot be used, by heavy paver's rammers. No breaks, steps or irregularities in the distribution of material or formation of the layers will be allowed, and the whole embankment is to be carried up evenly so as to make a compact and solid foundation.

PIPES—HOW LAID.

46. All pipes over eight inches in diameter shall be laid with a straight edge. One end of the straight edge shall be placed on the nearest grade peg and the other on the flow line of the pipe already laid, and the pipe shall be so adjusted as to be in cóntact with the straight edge throughout its length.

All pipes eight inches and less in diameter, except house branches, shall be laid in the following manner: A mason's line shall be tightly stretched parallel to the grade and slightly above the sockets of the pipes. This line shall be supported over the centre at distances not greater than twenty-five feet apart. The exact grade for each pipe shall be obtained by measuring down from this line to the invert of the sewer.

47. Especial care must be taken to lay the pipe to the exact grade and line.

48. All pipes, previous to being lowered into the trench, shall be fitted together and matched, so that when joined in the trench they may form a true and smooth line of pipes. No pipes shall be trimmed in any case. Pipes which do not fit truly shall be rejected.

JOINTS.

49. A gasket of oakum or other material approved by the Engineer shall be pressed into the joint around the entire circumference of the pipe to prevent the entrance of cement to the inside of the pipe. No joint shall be cemented until the gasket of the next joint in advance has been completed.

50. The cement shall be pressed into the space between the socket and spigot so as to entirely fill the space, and the bevel joint at the end of the socket shall be smoothly and evenly made. Special care must be taken to make perfect joints at the bottom of the pipe.

51. The excavation made for the socket of the pipe shall be filled with sand to support the cement firmly in position.

When the joint is completed great care must be taken not to disturb the pipes.

CEMENT.

52. The cement for filling the joints shall be pure fresh ground.......... cement, of best quality, with only enough water added to give it the proper consistency, and shall be mixed only as needed for use.

BRANCHES, "T'S," ETC.

53. The "Y" branches, "T's," lamp-holes, hand-holes, and man-holes shall be placed at points indicated by the Engineer. They shall not be covered until he has noted and recorded their exact position. The "Y" branches shall be elevated to correspond to the lateral sewers and house drains entering them. They shall be closed with an earthenware cap, and the space above the cap shall be filled with sand, covered with a thin coating of cement.

SPECIAL PIECES.

54. Special pieces, such as Y branches, curves, T's, etc., shall be made according to drawings furnished by the Engineer.

SEWERS TO BE KEPT CLEAN AND FREE FROM WATER.

55. All the pipes must be kept thoroughly clean, and no water will be allowed to flow through them, during the construction of the sewers.

56. When the trench is left for the night, or the pipe-laying is stopped by rain storms or any other cause, the ends of the pipes must be closed water-tight with bricks and cement.

57. When running quicksand or other treacherous ground is encountered, the work shall be carried on day and night, should the Engineer so require.

ARTIFICIAL FOUNDATION.

58. Whenever ordered by the Engineer, in writing, the contractor shall excavate to such depth below grade as the Engineer may direct, and the excavation shall be brought to grade with such material as shall be ordered by the Engineer; the extra work to be paid for upon the estimate of the Engineer.

59. If the contractor excavates below grade without orders, he will be required, at his own expense, to fill the excess of excavation with such material as the engineer may direct.

60. Concrete foundations shall be placed under the flush-tanks and man-holes.

ROCK CUT.

61. When blasting is resorted to for making the excavations, the trench shall be covered carefully on the top and sides with heavy timbers and plank, to prevent fragments of rock from being thrown out.

In rock cut, the rock shall be taken out of the trench to a depth of four inches below the bell of the pipe when laid. The refilling from the bottom of the trench to one foot above the bell of pipe shall be of earth, free from stones, or such material as shall be approved by the Engineer.

62. All damages or injury to persons or property resulting from blasting operations, or from neglect in properly guarding the trenches, must be paid by the contractor; and no compensation to said contractor for losses thus incurred will be allowed.

LAMP-HOLES.

63. Lamp-holes shall be constructed by placing an eight-inch "T" branch vertically in the sewer, and bringing it up to within one foot of the street surface by adding pipes of the same diameter. The top of the lamp-hole shall be protected by cover, as shown in the detail drawing.

MAN-HOLES.

64. The man-holes shall be constructed of hard brick, laid in cement mortar, and plastered outside with cement mortar and washed inside with pure cement. The thickness of the wall shall be eight inches. The form shall be a truncated cone (see drawings). The bottom shall be formed of concrete, and the top of the concrete shall be on a level with the bottom of the sewer pipe, and the top of the cover on a level with the street surface. Particular care must be taken in forming the bottom of man-holes to make the curves of tributary sewers as easy as possible. The top shall be covered with a perforated cast iron cover, with dust pan underneath. (See drawings.)

FLUSH-TANKS.

65. Flush-tanks shall be constructed of hard-burned bricks, carefully laid in cement mortar, so as to be water tight. They shall be plastered outside and inside with cement mortar. (For form, size and details see drawings.)

66. The emptying device for the flush-tanks shall be selected and purchased by the Commissioners and shall be properly set by the contractor.

67. The water supply pipe, within the flush-tank, and extending through the wall and one foot outside of the wall, together with a suitable brass stopcock for regulating the water supply, shall be furnished by the contractor.

BRICK MASONRY.

68. None but the best quality of whole, sound, well-shaped brick, burned hard entirely through, shall be used. They are to be culled when delivered upon the ground, and all bats and imperfect bricks are to be immediately removed from the work.

All bricks are to be thoroughly wet immediately before laying. Every brick is required to be laid in a full and close joint of cement mortar, on its beds, ends and sides, at one operation. In no case is mortar to be slushed in afterwards.

CEMENT MORTAR.

69. All cement mortar for man-holes, lamp-holes and concrete, shall be made of best quality of fresh ground....... ....cement and clean sharp sand, in the proportion of one measure of cement to two of sand. The sand and cement shall be thoroughly mixed dry, and such quantity of water added as to form a paste of the proper consistency. All mortar shall be fresh for the work in hand. No mortar that has begun to set shall be used. Every facility for inspecting and testing the cement shall be furnished by the contractor.

CONCRETE.

70 The concrete used on the work shall be made of three parts of cement mortar (made as described) and two parts of clean gravel, or broken stone. It shall be quickly and thoroughly mixed, and immediately deposited in place.

MATERIALS.

71. All materials shall be furnished by the contractor, and shall be subject to inspection and acceptance by the Engineer.

LENGTH OF SEWER.

72. The length of the sewer will be measured on the centre line of the completed sewer.

INTERPRETATION OF TERMS.

73. Wherever the word "Commissioners" is used in these specifications, it shall be held to mean the Board of Sewer Commissioners of the City of ....

Wherever the word "Engineer" is used, it shall be held to mean the Engineer in charge of the sewers, or his authorized assistant.

Wherever the word "Contractor" is used, it shall be held to mean either any contractor or firm of contractors, or any member of a firm, contracting for work herein specified.

GENERAL STIPULATIONS.

74. The contractor shall start the work at such points on the line of the sewer as the Engineer may from time to time direct, and shall progress from the outlet, or towards the outlet, at the option of the Engineer.

75. No pipes or masonry shall be laid in freezing weather.

76. None of the work shall be sub-let without the permission of the Commissioners.

77. The contractor shall also do such extra work in connection with his contract as the Engineer may in writing specially direct, and in a first-class

manner, but no claim for extra work shall be allowed unless the same was done in pursuance of a written order, as aforesaid, to do the work as such and the claim presented at the first estimate after the work was done. Extra work shall be paid for on a basis of 15 per cent. in advance of the actual cost of labor and material as determined by the Engineer.

78. Although the Engineer may assent to special means for prosecuting work in difficult cases, this will not relieve the contractor of the responsibility as to the result.

79. The contractor upon being so directed by the Engineer, shall remove or rebuild, or make good, at his own cost, any work which the latter shall decide to be deficiently executed.

80. No work shall be covered until it has been examined by the Engineer or inspector.

81. The contractor will be required to observe all City Ordinances in relation to obstructing streets, keeping open passage ways and protecting the same where exposed, and, generally, to obey all Ordinances, Rules and Regulations controlling or limiting those engaged on the work

82. At the suspension of any work the trenches shall be filled and the street left clean and free for travel.

83. The contractor shall give notice in writing, at least twenty-four hours before breaking ground, to all persons (Superintendents, Inspectors or otherwise) in charge of property, streets, gas pipes, water pipes, railroads or otherwise, that may be effected by his operations. And it is further agreed that the said part......of the second part shall not cause any hindrance to or interference with any such company or companies in protecting their said work; but that the said part......of the second part will suffer the said company or companies to take all such measures as they may deem necessary for the purpose aforesaid.

84. The Commissioners shall have a right to make alterations in the line, grade, plan, form or quantity of the work herein contemplated, either before or after the commencement of the work. If such alterations diminish the quantity of work to be done they shall not constitute a claim for damages, or for anticipated profits on the work dispensed with; if they increase the amount of work, such increase shall be paid for according to the quantity actually done, and the price or prices stipulated for such work in this contract.

85. If any person employed by the contractor on the work shall appear to the Engineer to be incompetent or disorderly, he shall, on the requisition of the Engineer, be immediately discharged, and such person shall not be again employed upon the work without the permission of the Engineer.

86. The work embraced in this contract shall be begun within......days after the award of this contract, and carried on regularly and uninterruptedly thereafter, with such a force as to secure its full completion by.............
......; but should the work be delayed or interrupted by the City, after the service of such notice, the contractor shall be entitled to an extension of time equal to the time of such interruption or delay, which shall be determined by the engineer; the time of beginning, rate of progress, and time of completion being essential conditions of this contract; and if the contractor shall fail to complete the work by the time above specified, the sum of.........per day, for each and every day thereafter, until such completion, shall be deducted from the moneys payable under this contract. This sum shall be in addition to any penalties otherwise specified.

87. No charge shall be made by the contractor for hindrances or delay from any cause during the progress of any portion of the work embraced in this contract.

88. No variation from the regular prices named in the proposal will be made or allowed, whether the material through which the trenches are excavated is hard or soft, or whether it is composed of rock, boulders, walls or common earth. The Board of City Commissioners will not consider themselves bound to notify or inform contractors where material that is hard or expensive to excavate occurs, or will be liable to be encountered. Furthermore no compensation for trenching done in excess of the orders of the Engineer will be allowed.

89. A watchman shall be employed on the work at night whenever in the opinion of the Engineer it shall be necessary.

90. House branches shall be laid to a point just within the curb lines where the Engineer shall direct.

91. Should any dispute arise between the Engineer and contractor as to the true meaning of the drawings or specifications in any point, or as to the manner of the execution of the work, or the quality of the work executed, the decision of the former shall be final and conclusive.

92. And the said................ ....
contractor, hereby expressly binds himself to indemnify and save harmless the City of............., from all suits or actions of every name and description brought against the said City, for, or on account of any injuries or damages received or sustained by any party or parties by or from the said............
....or his servants or agents, in the construction of said work, or by or in consequence of any negligence in guarding the same, or any improper materials used in its

construction, or by or on account of any act or ommission of the said.........
............................or his agents.

93. In consideration of the completion by said party of the second part, of all the work embraced in this contract, in conformity with the specifications and stipulations herein contained, and in strict accordance with the instructions of the Engineer, the City of.............., party of the first part, hereby agrees to pay to the said party of the second part, the prices named in the "PROPOSAL" which is hereto annexed, and which is hereby made a part of this contract.

94. Payments for the work shall be made monthly upon the estimate of the Engineer. Ten per cent. of the amounts due will be retained as a guarantee against poor workmanship and materials. One-half of this reserve will be paid as soon as the work is completed and accepted and the balance at the expiration of one year after the acceptance of the work.

In Witness Whereof, the City of...........has caused its name to be affixed by.................................thereunto duly authorized, and the said.................... ....party of the second part h........................hand, the day and year aforesaid.

ATTEST:

....

....

....

....

....

....

[FORM OF BOND.]

BOND.

Know all Men by these Presents, That we............................
....
....
are held and firmly bound unto the City of................. ....
in the sum of.......................... ....Dollars, lawful money of the United States of America, to be paid to the said City of..........
...................., or to its certain attorney or assigns, to which payment, well and truly to be made, we bind ourselves, our heirs, executors, and administrators, and each and every of them, firmly by these presents.

Signed and sealed with our seals, and dated at........................
......................this........day of..............................189..

The Condition of this Obligation is such, That Whereas, the said........
....ha....
entered into a contract with the city of..................................
bearing date the..........day of............................, 189.., which said contract is hereunto attached.

Now, Therefore, If the said.................. ....
shall well and truly keep and perform all the terms and conditions of said contract, on..............part to be kept and performed, and shall indemnify and save harmless the said City of ....,
as therein stipulated, then this obligation shall be of no effect, but otherwise it shall remain in full force and virtue.

.................................L. S.
.................................L. S.
.................................L. S.
.................................L. S.

CHAPTER IX.

CONSTRUCTION.

Before staking out the line it will be necessary to find out the location of whatever gas, water, and sewer pipe may have been previously laid. This is not always easily accomplished. Work of this kind is frequently done under the direction of the so-called "practical man," who scorns "theory and science," and whose sublime confidence in his own ability is only equaled by his capacity for engineering blunders, as exhibited in bad plans and worse construction.

One of the most annoying things to be met with in locating sewers is to find water and gas pipes running haphazard through the streets, having been put down without system or sense, and worse than all, to find that no map or record of their location has ever been made.

Importance of Record.—The value of the work will largely depend on the facility and accuracy with which the exact location, laterally and vertically, of every part of the system can be indicated; and hence in the construction notes such methods must be used as will be rapid, accurate in the greatest possible degree, and least liable to mistakes in recording.

The following described methods have been found to give good results:

Alignment.—First, let the centre line of the sewer be located carefully on the ground with a transit, making a study, as the line is extended, of the map of gas, water and sewer pipes previously referred to.

All measurements should be made with a steel tape, and all notes made to the centre line of the sewer as run. Since it would be impossible to preserve this line, however, during the construction, no stakes need be left in it, but stakes should be

set to the right or left a uniform distance of about one foot greater than half the width of the proposed trench. This will bring them within the space on the bank usually left clean for the workmen to pass and repass in handling material, etc. The position of stakes is shown in Plate I.

The stakes should be set at uniform distances of about twenty-five feet apart. They should be about one inch square in section, square on top, and of such a length that they can be driven flush with the surface of the street. Where extreme accuracy is required it will be well to indicate the precise point in the stake by a tack driven into its top; but ordinarily, with the size of stake indicated, this will be unnecessary. The offset line should uniformly be taken on the same side to avoid confusion, and the notes should indicate the side on which it is taken.

Reference Points.—The line is best located by observing to the nearest tenth of a foot the station which is intersected by the prolonged lines of brick walls or other permanent lines

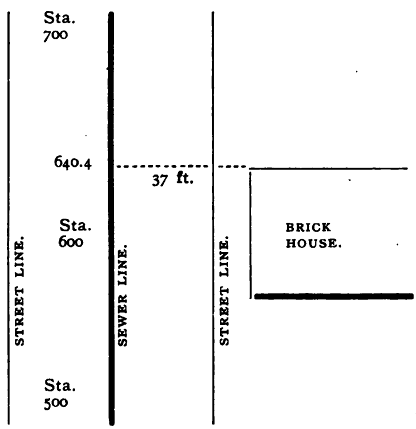


FIG 3.

which are clearly defined, and also the distance from the corner of the building, the line of whose wall is prolonged, to the centre

line of the sewer at the station observed as above. (See Fig. 3; the prolongation of the brick wall intersecting the true line at station 640.4, and being at this point 37 feet distant from the corner of the building.) This will be found a much more satisfactory location than the ordinary method of tie lines or focal co-ordinates, requiring less description in the notes, and giving a sharper determination of the point. It may be supplemented at street intersections and changes in direction, however, by the latter method with advantage.

Two rules should be kept in mind in this method of location, viz.: Never record a measurement to the offset line, as it is only for use temporarily. Never leave a permanent stake in the true line, as it may lead to confusion.

There will be no difficulty in finding the offset stakes, even though they be driven flush with the surface of the ground, as, having a starting point, nearly the precise location can be determined by measurement. When the streets are paved with stone pavement, a block can be removed and the stake driven, and then the stone replaced.

At changes in direction, the angular deflection should be recorded, and also the location of the intersecting tangents, with reference to prominent and permanent objects.

Curves.—When the angular deflection is slight, no curve will be required in the original location on the ground, but the notes should give the offset to be made from the intersection of tangents and from short stations equally distant from it on either side. The exact location of the centre line can then be determined by drawing a tape on the tangents either way from the intersection of tangents, and measuring the offset required from the proper points on the tape, with an offset rod.

When the angular deflection is considerable the curve should be run by transit or chord deflections in stations of twenty-five feet. Intermediate points can be interpolated in construction by ordinates from the chord.

The method above indicated, when faithfully pursued, will enable us to replace any point in the transit line with precision.

Transit Notes.—The transit notes should indicate approximately the distance from the sewer line to the buildings on either side, where they stand back from the street line. This may be taken by a good transit man with sufficient accuracy by the eye, aided by an occasional measurement.

The intersection of both lines of all crossing streets should be noted by station on the transit line, and also the offset from the transit line to angles in the street line. All crossings of streams should also be taken, and whatever notes are necessary to completely determine and indicate the physical characteristics of the territory.

The location should proceed from the outlet upward toward the higher levels of the system, and the various tributary branches should be tied to one another and to the main lines as often as possible, as a check on the work and as a guide in platting the finished map.

Level Notes.—The transit party should be followed by the leveler and assistants. The surface elevation should be taken on the true line, which can readily be obtained from the stakes left by the transit party by an offset measured by the leveling rod, or in ordinary cases can be determined with sufficient accuracy by the eye, after a little practice. The levels should be carefully checked at each bench-mark, as described on page 59. In cases where there is a sharp transverse slope to the surface of the ground, or when the buildings on one side of the street are considerably elevated or depressed below the street level, this should be carefully noted, and also the depth of basements, and any conditions, a knowledge of which will aid in giving a proper sewerage system to each building.

The level of all streams should be taken, and so far as it can be ascertained, the approximate level of the ground water. This can be ascertained with tolerable precision by observing the condition of wells bordering the street, when such can be found. The levels of water in these should be taken at intervals, and on both sides of the street, as the subterranean water surface may

have a sharp decline in the direction of its natural drainage basin.

In cases where it is probable that the construction work will shortly follow the adoption of a plan and where the physical character of the territory is sharply defined, and the drainage lines are apparent on a superficial inspection, the preliminary and final survey may be combined in one with economy.

Profiles.—The transit and level notes being complete, profiles of the several lines should be made to a large scale, showing the surface and grade lines, intersecting streams, etc. It will save the engineer much annoyance if the contractor be furnished a duplicate of the profile or a statement of the cuts at the several stations as he can then intelligently plan his work from the outset without further questions. The ordinary profile paper, known to the trade as Plate A, will be found suitable for this work, and a convenient scale will be one foot vertically for each one-fourth inch, and one hundred feet horizontally for each two and one-half inches, to which the Plate is adapted. Cuts can be taken from this scale with tolerable accuracy, and they will serve as a check on those found by computation.

Working Map.—The plan being definitely decided upon, and the profiles made as described, a rough map should be made for use in construction, showing position and size of sewers, location of man-holes, lamp-holes, flush tanks, and other accessories, and kept in the office for convenient reference during the progress of the work.

Note Books.—Each constructing engineer should be furnished with a field book, arranged something as follows:

LEFT HAND PAGE. RIGHT HAND PAGE.

Station.	Surface.	Grade.	Cut.	Construction Notes.
....	....	....	......	....
....	....	....	......	....
....	....	....	......	....

The four columns at the left should be filled from the notes in the office, and the construction notes should be taken as the work proceeds.

Construction.—It is generally best to commence the construction at the outlet and work toward the higher levels. When this is done, the spigot of each pipe is easily inserted in the socket of that already laid. There is also no tendency of the pipes to *crawl* away from the work or to open at the joints before the cement may be entirely set.

In some cases, however, where the grades are flat, and water is found in large quantities in the trench, the pipes can be laid from above downward with advantage, as the water can thus be drawn away from the pipe into the lower levels of the trench and then pumped out without interfering materially with the laying of the pipe. The pipe should be laid in each case with sockets up or toward the summits, and spigots down or toward the outlet; and when the work proceeds from above there is more difficulty in making proper joints and in inserting the gasket.

The pipe should be supported entirely on its cylindrical part, as shown in Plates I and X, a recess being formed to receive the socket and the cement joint.

Pipe Laying.—The organization of the gang for work may be as follows:

The earth can be removed from the trenches to a depth of about the centre of the pipe by common laborers. The pipe laying gang should be preceded by men trained to the purpose, whose business it is to shape the trench for the pipe. In laying the smaller sizes, the pipe layer will need no helper in the trench, but can receive the pipe from his helper on the bank, and place them unaided. In laying pipe of larger size, he should sit or stand astride of the pipes already laid, and his assistant should receive the pipes from above and assist in placing them.

The joints should be cemented by a person specially trained for the purpose. This can best be done by the hands encased in

rubber mittens or gloves, and they should be wiped something as a plumber wipes a joint.

After the joints are cemented, the pipe should be carefully bedded, and all Y branches carefully packed and covered by a trusty man in advance of the regular back-filling gang.

When the depth of excavation is considerable, and the streets narrow, or the buildings close to the street line, Y branches should be more elevated than when opposite conditions are found.

Various mechanical devices have been proposed for ensuring the concentricity of the pipes. It is doubtful if they are of any great benefit, however. Pipes which are not truly formed should be rejected. Pipes which have too loosely fitting spigots and sockets should also be rejected, as any imperfection in form is less apparent and the axes of the pipes when laid are less likely to coincide. Since the flow rarely rises above the horizontal diameter of the sewer, particular care should be taken to have its invert as perfect as possible.

With good management on the part of the contractor, sewers of vitrified pipe of small diameter, laid in trenches of the depth usually necessary, can be laid much more rapidly than sewers of larger diameter, the rate of progress being limited in either case by the work of one gang of pipe layers or brick layers. Rapid and carefully systematized work by the engineer is therefore required, who should take personal charge, as the decisions constantly needed in its progress, the locating and recording of junctions and similar work cannot be left to an inspector. A sufficient number of junctions should be inserted to meet all future demands. Connections by cutting into the pipes where no junctions are placed can be made with about the same facility as if the pipes were of plate glass, and if so made will ruin the sewers. A perfect record of everything pertaining to the work should be made for future reference.

Depth.—The depth to which sewers should be laid in the street will be determined by local conditions. In the closely built business portions of towns, however, where the ground floor space is valuable, property owners frequently desire to place

water closets, urinals, laundries, etc., in the basement, and although this is not a desirable place for them it sometimes becomes necessary to adopt this course as the lesser of two evils.

Pipes should never be laid under basement floors when it can be avoided, but should enter the basement just above the floor and be supported by substantial iron brackets or hangers.

In cases where it is necessary to locate plumbing fixtures in basements the following will be a reasonable allowance for the depth of the sewer in the street:

Depth of basement below street level, ...	9.00 feet.
Inclination of house sewer, 1-60 (50 feet), ..	.83 "
Diameter of street sewer (8 inches)........	.67 "

It will often be impossible to secure the desired depth. The problem then becomes to secure the maximum depth consistent with requisite grade, etc.

It is advisable in all cases to keep the sewers at least six or eight feet below the street surface in northern towns, to avoid water and gas service pipes and mains.

There is little danger of sewers freezing, even though they be laid quite near the surface.

Grade Line.—The pipe should be laid to line and grade indicated by stakes driven in the bottom of the trench, the top of the stakes being to exact line and grade. These should be set in advance of the final shaping of the trench, in the following manner: The line is determined by laying an offset rod across the trench at the offset stakes, which were set in the final location, and setting the stake in line by a plumb-bob. The stake should be driven to grade by a self-reading rod, read directly from the level whose elevation above the assumed datum should be carefully checked at each bench mark. No setting of grade pegs by measurement of cuts from the surface should be allowed. A convenient and cheap rod is shown in Plate I. Sixteen feet will be found a convenient length.

Bracing and Sheet Piling.—In many soils it will be necessary to protect the sides of the trench from caving by timber and braces. A very good method of doing this is shown in detail

in Plate IV. The iron screws will be found a great saving over the ordinary method of cutting timber shores, which, in many cases, can be used but once, and are liable at any time to become loosened. The iron screws can be used any number of times, will fit any width of trench within reasonable limits, can be quickly placed and removed, without jarring the trench, and can be tightened at any time, without the trouble and risk of removing a short one and inserting a longer one in its place. These screws can be manufactured at present prices for about $2.00 each. One hundred screws of assorted lengths make a fair outfit for one gang of pipe layers in ordinary work.

The method of bracing and sheet piling can be better understood from a study of the drawing than from a written description. It requires considerable experience to place it and remove it quickly and without damage to the material. By the use of this method of bracing and sheet piling, the driest sand and gravel can be excavated about as cheaply as soil sufficiently tenacious to support itself, in trenches exceeding seven or eight feet deep, though the sides of the latter need no protection.

The drawing shows two rows of piling; these can be increased to three or four, or still more, if necessary. Up to a depth of eight or nine feet one row of piling, in connection with the horizontal planking, will be sufficient.

The following bill of material may be of service:

SINGLE ROW OF SHEET PILING.

This will be sufficient up to a depth of eight or nine feet.

Each section of sixteen feet in length requires the following material:

LUMBER.

10	pieces	2x10,	16	feet	long.	550 feet B. M.
36	"	1x10,	7	"	"	
4	"	2x 8,	7	"	"	
4	"	3x 6,	16	"	"	
4	"	3x 6,	1	"	"	

True Photograph of Sheet Piling.

IRON SCREWS.

2	screws	36	inches	long (closed).
2	"	30	"	"
2	"	24	"	"

The above bill requires a trench four feet in width at the top, and gives a clear space at the horizontal diameter of the pipe of forty inches, and between the horizontal timbers a clear space of thirty-four inches. This will be sufficient for a pipe eighteen inches in interior diameter. For larger sizes the length of the screws must be increased, and for smaller sizes the trench may be somewhat narrower.

DOUBLE ROW OF SHEET PILING.

This will be sufficient up to a depth of thirteen or fourteen feet.

Each section of sixteen feet in length requires:

LUMBER.

10	pieces	2x10,	16	feet	long.	829 feet B. M.
72	"	1x10,	7	"	"	
8	"	2x 8,	7	"	"	
8	"	3x 6,	16	"	"	
6	"	3x 6,	1	"	"	

IRON SCREWS.

2	screws	36	inches	long (closed).
1	"	30	"	"
1	"	24	"	"
2	"	20	"	"
2	"	14	"	"

The above bill is figured for a trench four feet wide at the top, and gives a clear space at the horizontal diameter of the pipe

of thirty inches, and a clear space between the lower horizontal timbers of twenty-four inches. This will be sufficient for pipes of twelve inches in diameter and less. For larger sizes the width of excavation should be increased.

In heavy ground the length of the horizontal timbers may be reduced to fourteen feet or twelve feet with advantage, or an extra set of uprights may be used, dividing the sixteen foot sections into thirds instead of into halves.

Inspection of Material.— All sewer pipe should be inspected as fast as it is delivered at the work, and imperfect pipe should be plainly and indelibly marked and immediately removed. The engineer should also carefully scrutinize all pipes as they are passed to the pipe-layer, making sure that none which may have been broken since the formal inspection are laid in the trench. The subsequent breaking or giving way of a single section of pipe may cause a great amount of damage.

All other material should be inspected by the engineer in a similar manner, and that which is unfit for use promptly removed.

Location of Y Branches.—Property owners should be consulted as to the position in which they wish their Y branches placed, and it would be well to send them somewhat in advance of the construction a printed notice. If no return is made by the property owner, the engineer should locate the junction as appears most convenient for the property.

The position of all Y branches should be located by station, specifying whether they are north or south, east or west. Any other location is unnecessary and confusing. The location is best made from the centre of the opening, as shown in Plate I. This should be taken to the nearest tenth of a foot, and a plumb-bob should be used to transfer the point to the surface.

Artificial Foundation.—When very treacherous quicksand is encountered it will be necessary to support the pipe on piles or blocks until the earth can be tamped around it. When soil of a less treacherous nature is encountered it may be sufficient to remove the soil somewhat below the grade line and replace with clean gravel.

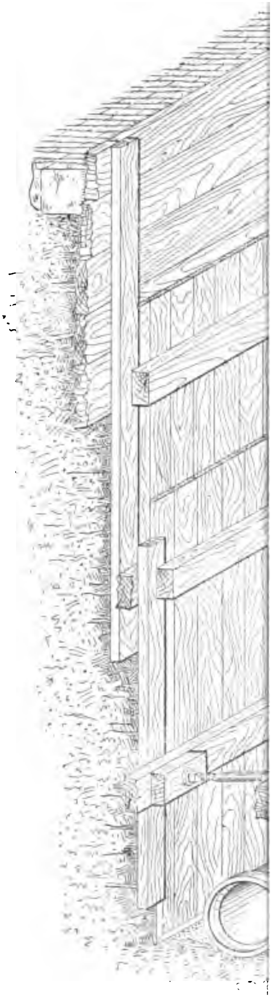
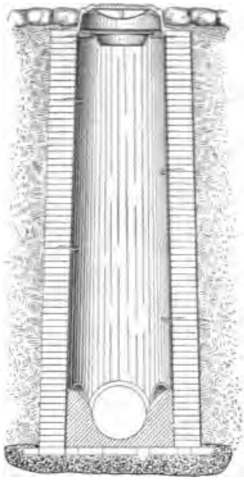
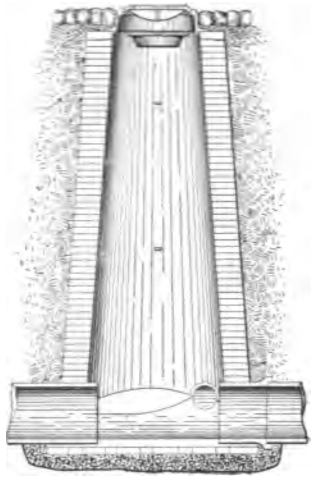
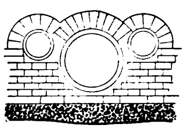


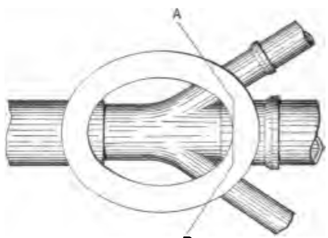
PLATE V.

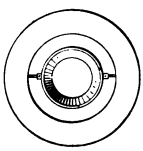


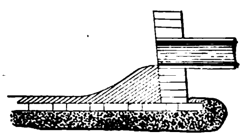




SECTION ON A B

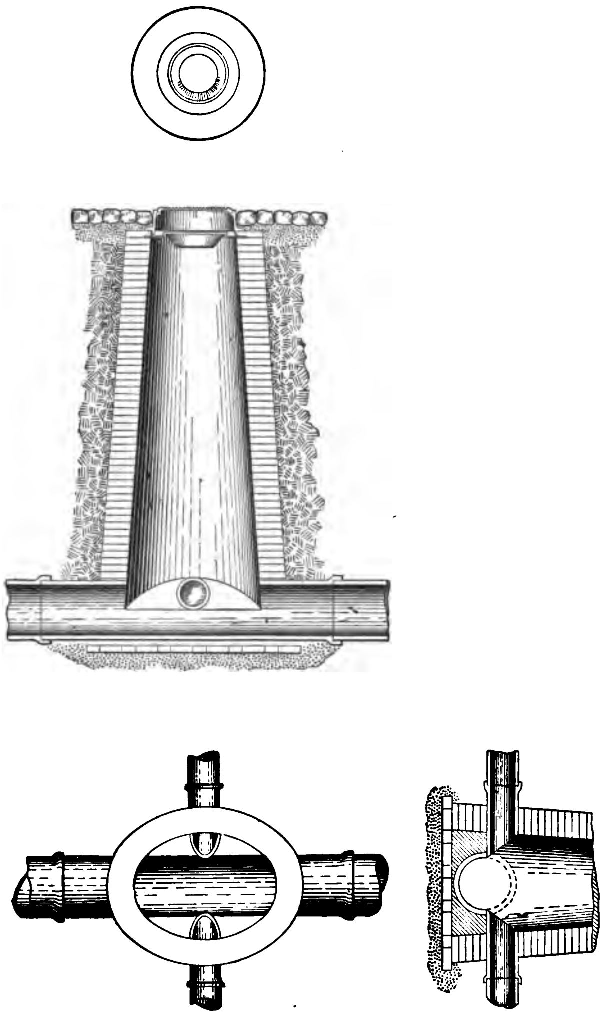






DETAILS
— OF —
MAN HOLE.

PLATE VI.



DETAILS OF MAN-HOLE.

Particular care should be taken to secure a firm foundation for man-holes, flush-tanks and lamp-holes, as their greater weight may cause a settlement which will break the pipes.

Man-Holes.—Man-holes should be built with an eight-inch brick wall, as shown in Plates V, VI and VIII. They should be plastered outside and inside. The iron cover with which they are surmounted should weigh from 300 to 500 pounds. The style shown in Plate IX has given good satisfaction when made to weigh 350 pounds. It has the following advantages: The least possible surface is exposed to traffic. The impact of passing wheels comes well within the base. The interior downward projecting rim prevents any loosened brick from falling into the sewer.

It is usual to hang a dust-pan below the perforations in the cover to catch the street detritus which may work through them. With good grades, however, there will be no danger of stoppage from this source when they are omitted.

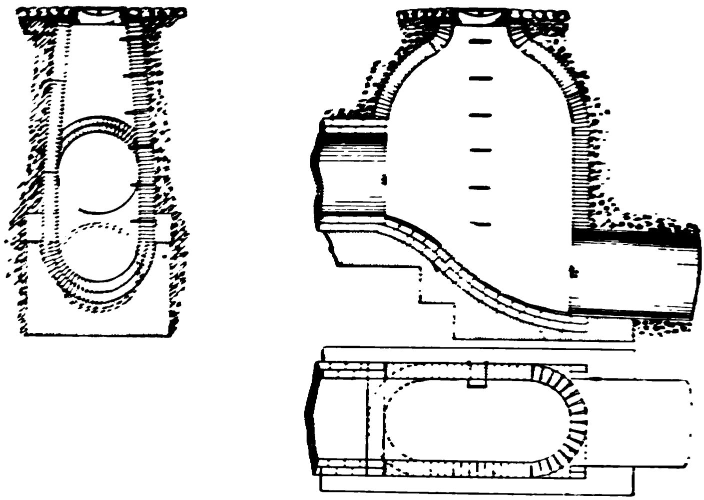
The method of forming the bottom of man-holes to preserve the proper cross-sectional form of the flow is shown in section. The method of connecting a sewer of small diameter with a larger one is also shown. Unless particular care is taken in forming these curves, solid matters will be stranded in the man-holes and become offensive.

Iron steps may be built in the wall, or a light, portable ladder used in ascending and descending. The steps are most convenient, but are liable to collect street detritus falling from above.

Flush-Tanks.—Flush-tanks should be built with an eight-inch brick wall, and plastered inside and outside with cement mortar. The upper courses of both man-holes and flush-tanks are exposed to the action of alternating frost and moisture in an unusual degree, and to the constant impact of vehicles, and with the best of material a four inch wall is not sufficiently durable.

The interior of the flush-tank should be connected directly with the sewer, independently of its discharge, by a pipe of large diameter, as shown in the Plates following. This will induce a

PLATE VII.



OUTLET CHAMBER.

current of air flowing along the crown of the sewer from the lower levels to pass into the tank and out through the perforations in its cover. No other protection against frost is needed. This is also a material aid in the ventilation of the sewers. All flush tanks should be supplied with a dust-pan.

The various types of flush-tanks will be more fully discussed in the chapter on flushing and ventilation.

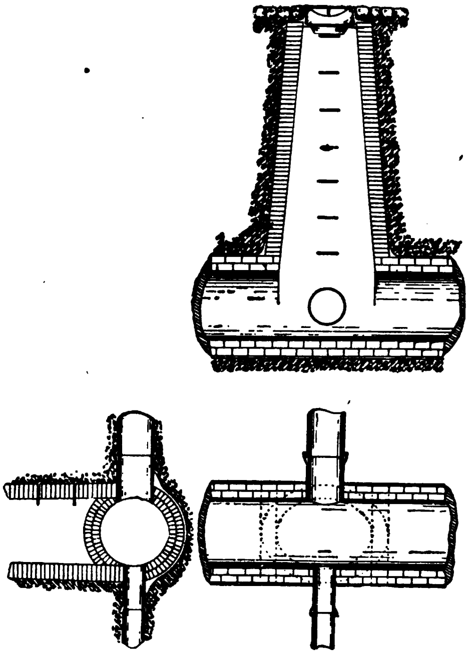
Lamp-Holes.—Lamp-holes should have a concrete bed under them to prevent settlement. They should be carried up as the trench is filled, and care must be taken to keep the sections vertical.

Care must be taken in locating man-holes, flush-tanks and lamp-holes to avoid gutters, crossings and other objectionable locations.

Upon leaving the work for the night, the ends of the pipe should be well cemented up as a protection against possible rain storms.

House Sewers.—Experience with sewers of the Separate System demonstrates that stoppages in the house sewers are

PLATE VIII.



MAN-HOLE—BRICK SEWER.

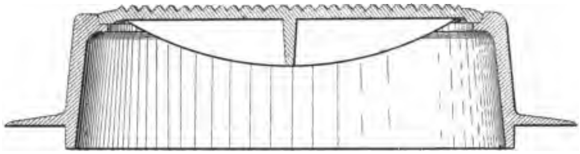
much more frequent than in the laterals; and the point in the house sewers which are particularly liable to obstruction is at the junction with the street sewer. Particular care should, therefore, be taken in the construction at this point. The Y branch should be properly elevated so as to bring the invert of the house sewer above the ordinary flow line of the street sewer, as shown in Plate X. The curve should have a sharp grade and particular care should be taken to have the spigots put squarely into the sockets and the gasket well placed. No cutting and

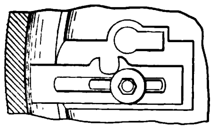
trimming of the pipe should be allowed, as it is impossible to make smooth joints of terra cotta pipe in this way. Curved pipe always warps unevenly in the kiln, and from an ordinary stock there will be no difficulty in selecting a curve suitable for any reasonable case. Three or four of these, slightly varying in radius should always be at hand.

A very common defect is to allow the centre or belly of the curve to drop down and open the joints before they are hardened, or to do the refilling in such a manner that the subsequent settlement of the trench breaks the joints or pipe. This can be avoided by thoroughly ramming the earth up to the horizontal diameter of the curve as it is laid and water-tamping or ramming in layers above this.

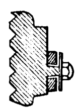
House drains can be very nicely laid in favorable ground with an ordinary carpenter's level placed on each pipe as laid, one end of the level being supplied with a graduated slide and set-screw, by which is set off the fall corresponding to one length of pipe.

PLATE IX.



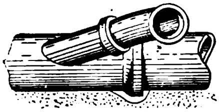


LOCK

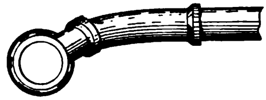


IRON COVER,
MAN HOLE
—AND—
FLUSH TANK.

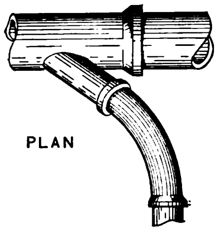
PLATE X.



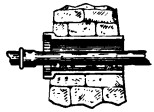
ELEVATION



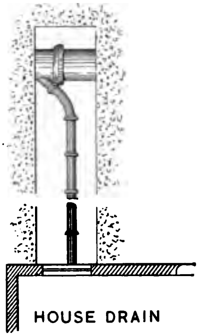
SECTION



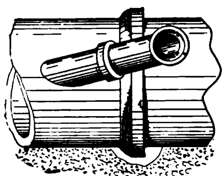
PLAN



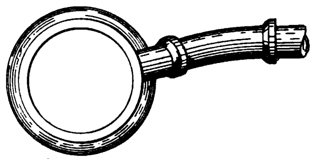
IRON PIPE
through House Wall



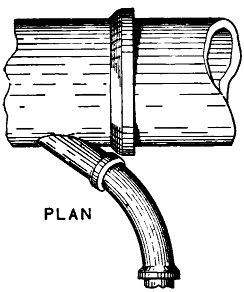
HOUSE DRAIN



ELEVATION



SECTION



PLAN

BRANCHES, CURVES

—AND—

HOUSE DRAINS.

CHAPTER X.

FLUSHING AND VENTILATING.

In the Combined System.—Any one seeing the volume of warm vapor rising from the man-holes of an ordinary combined sewer on a cold morning will get some idea of the immense quantity of gas which constantly rises from a sewer; and if he once gets a smell of the ascending column he can form some slight conception of its composition.

An examination into the condition of the sewers will, in most cases, at once show the cause of this enormous evolution of gas.

In a large majority of towns which have been thus far sewered in the United States the Combined System of sewers has been employed. The sewers are designed to carry not only the sewage of the town, but also the storm water from the roofs, yards and streets. Under these circumstances the size of the sewer is determined solely by the amount of storm water to be provided for; the amount of sewage being so small in comparison that it may be disregarded.

In fair weather, and especially in the long continued dry weather in summer, the sewage forms only a very small stream in comparison with the capacity of the sewer. This comparatively small amount of sewage is spread out on the bottom of the large sewer and the stream is shallow and sluggish.

Since the capacity of a stream to carry solid matter depends upon its depth and velocity it is readily seen that the solid particles in the sewage soon get stranded and the sewer becomes foul even where street refuse is rigidly excluded by the catch basin, which is seldom ever the case.

The storm water from the streets usually carries with it a large amount of detritus, straw, leaves and sticks. As the flow in the sewer produced by the storm slackens this solid material

is stranded, forming small dams in the sewer. These hold the sewage in pools, where it decomposes and sends off immense volumes of sewer gas.

Sewer gas contains sulphuretted hydrogen, carburetted hydrogen, nitrogen, ammonium sulphide and fœtid organic vapor.

Besides these gases, and quite as much to be dreaded, are the disease producing micro-organisms, commonly known by the name of bacteria, which abound in the warm, moist air of the sewers and are carried wherever the sewer gas penetrates. Several diseases are known to be produced by bacteria, and it is highly probable that the list will be increased as our knowledge in this field is extended.

In any place the struggle for life is between the bacteria and the human being. It is a survival of the fittest in any environment. Where sanitary matters are properly attended to and the environment is favorable for man it will be unfavorable for the bacteria, so the man will live and the bacteria will die. But where sanitary laws are disregarded and the environment is unfavorable for man it will be favorable for his enemy, and the bacteria will thrive and the man will die.

The question arises—what remedy can be applied to improve the condition of the sewer, and to prevent or diminish the dangers to health from this source?

Two things are needed in order to accomplish this end: flushing and the ventilation of the sewer. Thorough flushing will carry out the accumulations of solid matter and dispose of the pools of putrefying sewage. Fresh sewage is not very offensive, and if it can be carried rapidly to its outfall before decomposition sets in it will cause very little trouble either by becoming obnoxious or dangerous. It is the standing pools of decomposing sewage which causes most of the trouble.

Flushing may be accomplished in several ways. One of the simplest of these is to dam up the sewage by gates in the sewers until the sewers are nearly or quite full and then suddenly release it, causing a full, strong current in the sewers. Care must be taken not to hold the sewage until it backs up into the cellars

and basements along the line. To prevent the possibility of this, gates which only partly fill the sewers are used, so that when the sewage rises to a certain height it flows over the gate. Automatic gates are also used which turn on a horizontal axis placed below the center of the gate, the top turning outward away from the confined sewage. When the sewer becomes nearly full, the pressure on the part of the valve above the axis being greater than on the smaller section below the axis, the valve opens outwardly and releases the sewage.

The principal objections to the use of gates in the sewers are that that there is a tendency to deposit the solid particles on the bottom of the sewer where the sewage is impounded, and that the method cannot be applied to the upper ends of the sewers.

At the upper ends other devices must be resorted to. One is to collect the sewage in tanks, which are discharged automatically when full. Another is to use automatic flushing tanks filled with water, either by collecting rain water from the roofs, or from the public water works. When the water supply of a town is abundant the problem of flushing sewers can usually be easily solved.

In any Combined Sewer there will be a certain amount of organic matter smeared by the floods on its interior surface above the ordinary surface of the sewage, and the decomposition of this is constantly going on, developing considerable volume of gas. Added to this is the gas generated by the stagnant sewage held in pools by the obstructions in the sewers. If there are no openings in the sewer the traps in the houses would be forced by the pressure of the gases produced. Openings are absolutely necessary and wherever there is an opening the gas will escape. To dispose of this gas or to mix it with so large a volume of air as to render it harmless is the problem which presents itself.

The ventilation of a system of large sewers is a difficult task, and up to date it has not been satisfactorily done. One of the best authorities after careful investigation gave it as his opinion

that the only practicable plan was—to use his own words—"to just let the stink out in the middle of the street."

The use of high chimneys has been strongly recommended, and they have been experimented with to a considerable extent.

It has been quite confidently stated that as some of the gases found in sewers are lighter than air there will always be an upward draught in the chimney without any artificial aid. Unfortunately this is not the case, and to insure a constant current of air from the sewer up the chimney some means must be employed to secure a draught. This may be accomplished either by a fire at the foot of the chimney or a fan or screw in the chimney which is operated by a steam engine or other power. When the fire is used the sewer gas is usually passed through the fire. In this there is an element of danger, as leaks from the gas mains into the sewer are quite common and explosions from this cause have occurred.

Owing to the numerous openings into the sewers each chimney affects only a limited area, so that an extended system of sewers would need many chimneys. The cost of these chimneys and of running the fires in them prohibits their use, except in special cases. This system can be made efficient if we disregard expense, but engineers soon find that the item of expense is one of the most important considerations in any engineering project, especially if it relates to sanitary matters which are to be decided by the public.

Another plan is to ventilate the sewers by running an untrapped branch up through each house, relying upon the heat in the house to create an up draught in the pipe. This would be an efficient way of ventilating sewers, but it greatly increases the danger from them. A leak in the soil pipes, or the emptying of a trap by evaporation or syphonage (and both of these contingencies are much more common than is usually supposed) makes the house itself a ventilator for the sewer.

The rain water conductors have sometimes been used as sewer ventilators, but this releases the sewer gas in too close

proximity to the windows of the upper story of the house and is a dangerous practice.

One of the best plans is to carry up an untrapped pipe on the outside of the house to a sufficient height above the roof. If this plan could be generally adopted on any line of sewers it would afford one of the best solutions to the ventilation problem.

Various chemical processes for treating sewer gas in the sewers have been proposed, such as liberating chlorine gas, or sulphurous acid in the sewers. These methods have been tried on a small scale but the results have not thus far been encouraging.

A more successful plan has been to purify the sewer gas as it comes from the sewers by passing it through loosely packed charcoal. This has been tried on a large scale and has been fairly satisfactory although quite expensive.

A patent was taken out in 1858 for purifying sewer air by passing an electric current through it.

In the Separate System.—We have thus far been dealing with the "Combined System" of sewers. Where the Separate System is employed the problems of flushing and ventilation are materially simplified.

As has been already stated the amount of sewage is so small in comparison with the storm water as to be neglected entirely in computing the sizes needed in a Combined System. This being the case it is readily seen that the necessary size of separate sewers is small in comparison with those of the Combined System, and hence much less water is needed for flushing.

Again, since the flow of sewage is approximately constant and not fluctuating between the wide limits of the flow of storm water, the sizes of the pipes may be designed so that the flow of the sewage will keep the mains in proper condition, while the upper ends can easily be flushed by means of automatic flushing tanks of small size, compared with those needed on the large sewers of the Combined System.

A tank holding about two hundred gallons, placed at each dead end and adjusted to discharge once every day will keep the sewers well flushed.

To thoroughly flush a sewer requires a volume of water sufficient to fill the sewer for a considerable distance. The best results would be obtained if the sewer could for a time be filled its entire length, so as to flush all of the upper part of the pipe as well as the lower. This would not only cleanse the pipe, but materially aid in its ventilation by securing an entire change of air in the sewer.

If the sewers be designed to run half full of sewage during the hours of the greatest demand upon them, then sufficient water may be introduced to complete filling the pipes; that is, the amount of water for flushing may be equal to one-half of the capacity of the sewer. The difficulty of adjusting the amount of water for such complete flushing arises from the fact that the flow of sewage is not uniform. The maximum flow for a short time, under certain circumstances, may almost fill the pipe; now if arrangements are made to admit sufficient water to half fill the sewers at the time of maximum flow of sewage, the pipes will be surcharged and there will be danger of the sewage setting back into the houses.

When flush tanks are used to flush the sewers, if the discharge from the tank is sufficiently rapid, the flushing will be thorough, for a greater or less distance, depending upon the grade of the sewer. Gradually, however, the water will lose its velocity, and the flushing effect will be less and less until it amounts to but very little. Some means should be provided for giving at intervals a long continued flush. Especially is this the case where the fall is small and light grades a necessity, and where the effect of a flush-tank will be reduced to its minimum. This long continued flush may be given in two ways, either by admitting roof water, or by arranging to connect the sewers with the water mains.

Roof Water.—The storm water from the roofs may be utilized for flushing by connecting a limited number of rain water

conductors with the sewers at the upper ends of the lateral branches.

When roof water is used for flushing a difficulty arises in adjusting the amount of water to be admitted. When the sewers are first completed, much more water will be needed to flush them than will be required after their use has become general, and the flow of sewage has more nearly reached its maximum. But having once permitted the roof water from any building to be turned into the sewers it is difficult to shut it out when the proper time comes, so that to avoid trouble, no more roof water should be turned into the sewers at first than will always be needed.

If the sewers are designed to run one-half full of sewage during the hours of greatest flow then the roof water introduced for flushing should be a little less than one-half of the capacity of the sewers.

When the sewers are flushed by connecting the dead ends of the sewers with the water mains, the amount of water can readily be adjusted to suit the requirements in each case. The water from the mains may be admitted to the sewers by a direct pipe connection, provided with a suitable valve, or it may be taken from a hydrant and carried through a hose to a lamp-hole at the dead end of the sewer, which in this case should be constructed as shown in Plate I.

As the small sewers are of smooth earthenware pipes they are much easier kept clean than the rough interior surfaces of the large brick sewers and flushing will be more effective.

The ventilation of the separate sewers is a much simpler matter than in the case of the Combined System. When properly designed and constructed there are no pools of decomposing sewage standing along the lines, and as a consequence there is much less evolution of gas and hence much less need of special appliances for ventilation.

The rush of water from the flush tanks changes the air in the upper ends of the sewers, and the fluctuations of flow in the mains is an important factor in changing the air in the sewers by

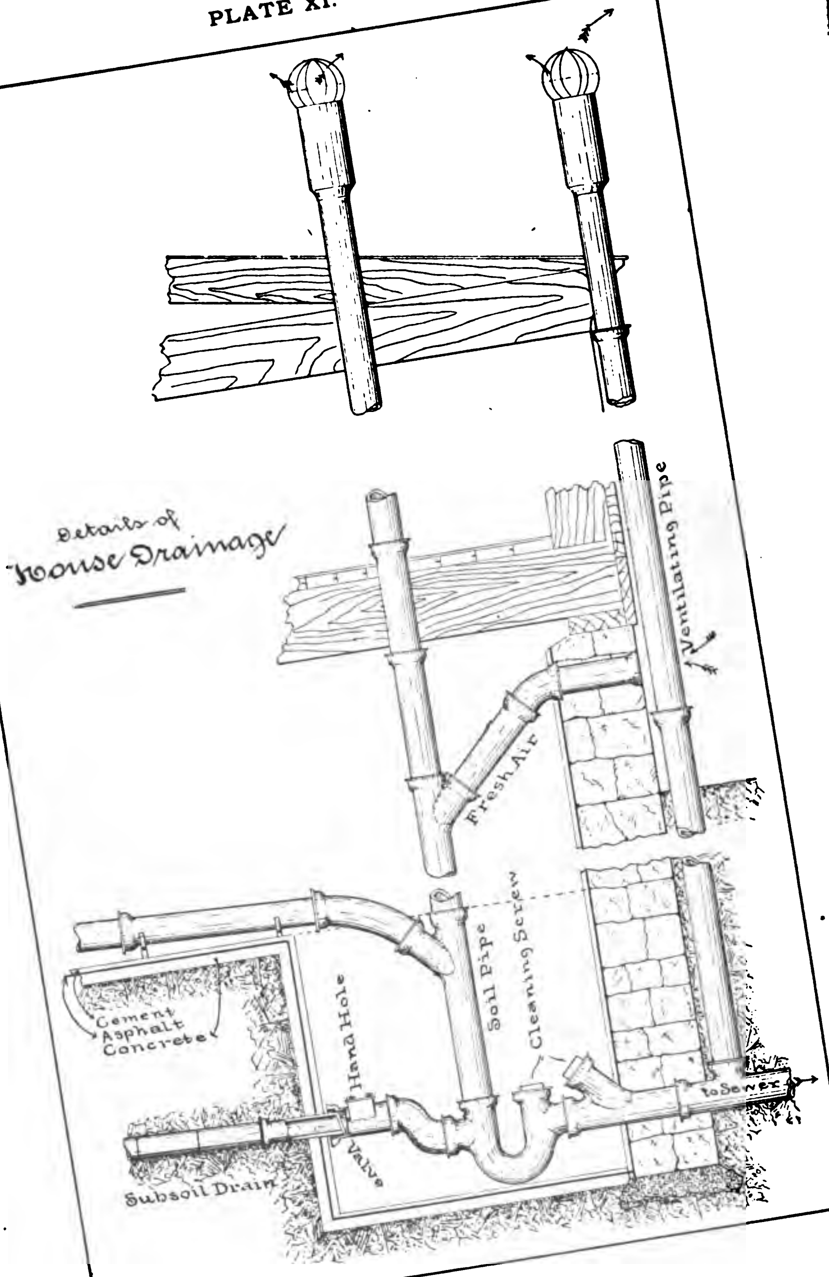
driving out the foul air as the sewage rises at the time of its maximum daily flow, and refilling the pipes with pure air as the flow falls to its minimum.

Any of the methods of ventilation which can be used on the Combined System are available for the Separate System and, as the amount of air to be moved is much less they will be more effective.

One of the most important parts of a system of sewers, and one which demands the attention of each householder, is that portion which is on each ones private ground. That is, the branch sewer leading from the house to the street. This part, at least, may be kept properly flushed and ventilated by the owners of the property without waiting for official action by the authorities.

A small automatic flush tank, holding from thirty to fifty gallons, adjusted to discharge once a day, and placed so as to empty into the ~~solid~~ pipe above the highest fixture in the house will keep the house drain flushed clean.

PLATE XI.


Details of
House Drainage
Ventilating Pipe
Fresh Air
Soil Pipe
Cleaning Screw
Hand Hole
Cement
Asphalt
Concrete
Valve
Subsoil Drain
to Sewer

The man-holes, flush-tanks and lamp-holes; when provided with perforated covers, as shown in the plates, will assist in the ventilation for the street sewers of the Separate System. The house drains, however, need some special arrangement for that purpose. An opening from the house drain to the air is necessary, not only for ventilation but to prevent emptying the traps by syphoning when the sewer is flushed.

The simplest method of accomplishing the ventilation of the house drains and at the same time of the sewers themselves, is to extend the main drain upward and out through the roof, unbroken by a trap in any portion. In this case it serves the double purpose of soil and ventilating pipe, and the air which passes into the street sewers at man-holes supplies the draught upward along the street sewers, and out through these and their upward extensions. In this case the isolation of the interior of buildings from sewer air depends solely upon the trap under each fixture. Where street sewers are properly constructed on the Separate System, and properly cared for, this method has proved entirely satisfactory. It certainly has great advantages in simplicity and facility of arrangement.

Where the sewers are built on the combined plan the method of isolation shown in Plates XI and XII is to be preferred. This diverts the foul air currents from the interior pipe and provides a supply of fresh air for the upward current through the soil and ventilating pipe. If the street sewers are not properly ventilated at frequent intervals, either by the upward extension of exterior or interior unobstructed pipes or otherwise, there may be reasons for believing that an isolated one may draw from too wide a territory and prove offensive. In this case it is advisable to dispense with any vent pipe communicating directly with the sewer.

If we could be perfectly certain that all the drain, waste and soil pipes were perfectly gas tight throughout their whole length, and would remain so, and that no fixture traps would ever be emptied by syphoning, evaporation, capillary attraction, or any other of the many ways by which traps *do* get emptied, we might safely use untrapped house drains. But taking the conditions

as they are, it seems to be taking too great a risk to ventilate the public and private sewers *through* the dwellings.

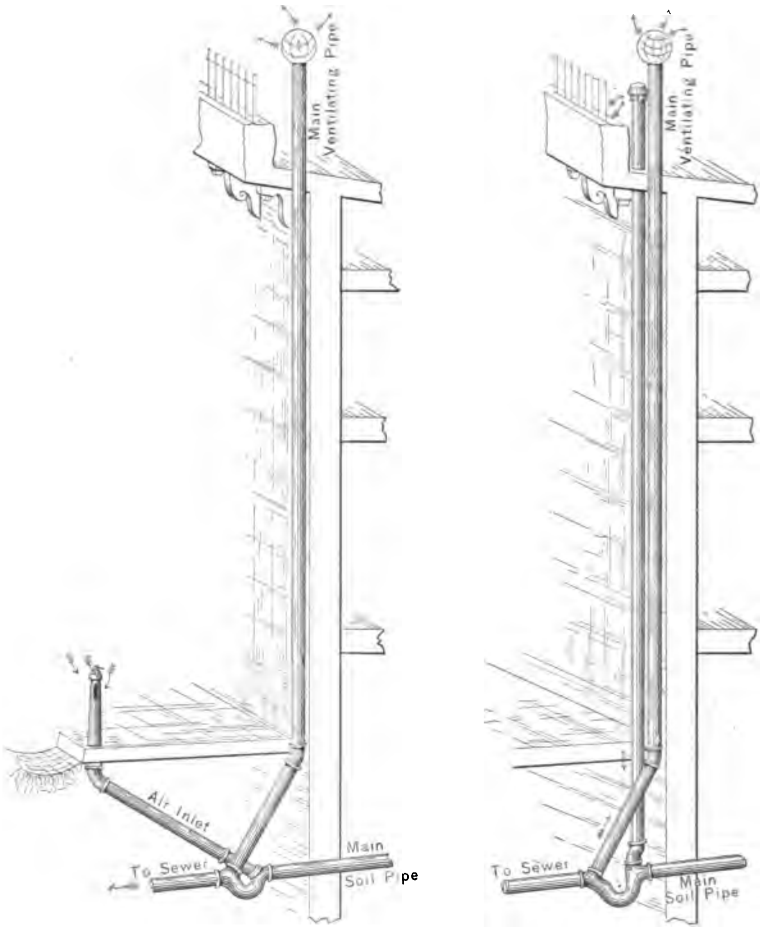
S. Stevens Hellyer, the well known sanitary engineer, writes as follows:

"Where the drains (house drains) are carried direct into the sewer, without traps, the houses, through the sewer, are brought into direct communication with each other, *i. e.*, the air in the drain of one house can pass into the drain of another house. Contagious diseases—typhoid or what not—may be infecting a house, and however isolated it may be from other houses above ground, it would not be so *under* ground with such a system. The untrapped drains branching into the sewer would form a subterraneous passage for the bad air or disease germs—coming from the stools of the infected patients—between house and house. But when each house drain is trapped off before entering the sewer, an all but impassable barrier would be placed between the drains, so that the houses would be as much isolated under as above ground."

If every house could be thus provided with the means of flushing and ventilating the whole problem of the flushing and ventilation of sewers would be simplified. The combined action of the flush tanks in the houses would flush the sewers, and the provision for ventilating the house drains would supply the needed ventilation of the sewers.

Man-holes and flush-tanks are liable to be covered with snow or mud at times and their efficiency as ventilators interfered with. If all house connections are made in the way above described—that is, if there is a free communication between an upright ventilating pipe on each premises and the sewer proper—we have substantially a horizontal pipe having at frequent intervals vertical pipes leading from it. These vertical pipes are of varying lengths and their upper ends are at different elevations, covering a range of several hundred feet, perhaps. These vertical pipes are also subjected to different conditions. For instance some of them are within buildings near artificial heat, some of them are at the south side of buildings where the sun will effect them, some on the north side where the temperature is lower, some of them are short and some are long. In short, the conditions are such that there cannot be an equilibrium of pressure throughout the system. Now, if the openings at the mouth of the sewer, at

PLATE XII.



MAIN VENTILATING PIPES AND TRAP.

the man-holes and flush-tanks are relatively large enough, and the air space along the sewer toward the higher levels where the house connections are numerous, is relatively large enough, it may happen that there will be an upward current in all the house ventilating pipes, the air being supplied, of course, through the openings along the sewer proper. It is probable, however, that this rarely occurs for the reason that the combined section of the ventilators is many times the section of the air passage in the sewer proper and consequently any difference in pressure that may be induced in the ventilating pipes by the causes above cited, is more easily restored by downward draughts in some of the ventilating pipes. It may thus happen that many of the short, cool ventilating pipes, particularly at the lower levels have, some of the time at least, a downward draught and that the total volume of air which passes through the system at various points is greater than could be supplied through the outlet, man-holes, etc., at the velocity which would be likely to be induced.

Automatic Flush Tanks.*—Flush-tanks are used either to collect the sewage and discharge it rapidly at intervals for the purpose of flushing the sewers, or to collect and discharge clean water for the same purpose. They should be automatic in their action.

This regular and automatic flushing is peculiar to the Separate System, and the diminished size of the pipes renders it very effective. It sweeps down all deposits and stranded matter from the remotest portion of the system into the mains, and the aggregate of these discharges in the mains from tanks differently timed sweeps it on to the outlet. The more regular flow in the Separate System and consequent immunity from variations in air and pressure space reduces the danger of forcing traps. The smaller air space increases the efficiency of all openings in relieving any pressure resulting from such variations, and also increases their efficiency as ventilators.

*The following descriptions of flush tanks are taken mainly from the manufacturers' catalogues. Prices of some of the leading tanks are given in the supplement.

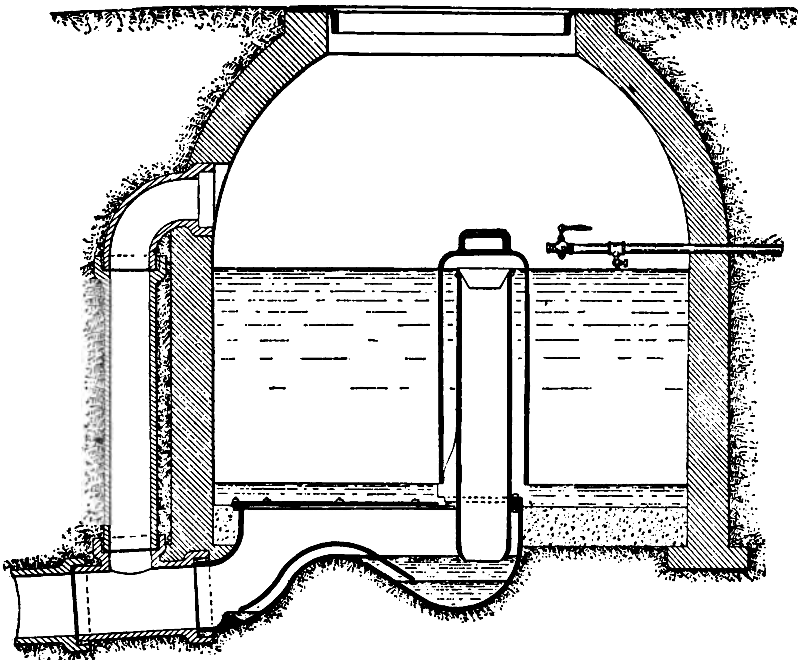
There are many forms of automatic flush-tanks, most of which may be classed under the four following varieties: 1, Tilting Tanks; 2, Syphon Tanks; 3, Valve Tanks; 4, Collapsing Tanks.

Tilting tanks are so designed that as they fill the centre of gravity is changed, until finally the equilibrium of the tank is destroyed and the tank tilts over and empties itself. The tank is so adjusted that when empty it returns to its proper position. A tilting tank on a small scale is shown attached to the long leg of the syphon in Van Vranken's flush tank, Plate XIV.

Syphon tanks are discharged by means of a syphon. They differ in the devices for starting the syphon. In places where the sudden rush of a considerable quantity of water can be secured, no device is necessary. Where house sewage is collected in tanks for flushing, the rush of water caused by emptying a bath tub, wash tub, etc., will be sufficient to start the syphon. But where the tank is filled by a stream of water small enough to fill a tank holding from one to two hundred gallons only once in twenty-four hours, some special arrangement will be necessary to start the syphon. This can be done by means of a small tilting tank on the long leg of the syphon, as in Van Vranken's tank; by a supplementary tank and syphon, as in Field's; by a ball cock, increasing the flow when the tank is nearly full, as in Vibbard's; by having the long arm of the syphon movable, as in Landon's; by a collapsing disk or tube, as in Chaplin's by an automatic valve on the long leg of the syphon by an aspirator; and in various other ways.

Field-Waring Flush-Tank.—The syphon invented and patented by Rogers Field and improved by Col. George E. Waring Jr., consists (in the form shown) of an annular intaking limb, and a discharging limb at the top of which is an annular lip or mouth piece, the bottom of which is tapered to less diameter. The discharging limb terminates in a weir chamber which when full to its overflow point just seals the limb. Over the crest of the weir is a small syphon whose function is to draw the water from the weir chamber and thus unseal the syphon. At the

PLATE XIII.



FIELD-WARING FLUSH-TANK.

lower end of the small syphon is a dam or obstruction to prevent its breaking. The main syphon is brought into action (on the tank being filled) by means of a small stream of water flowing over the annular mouth piece and falling free of the sides of the discharging limb. As soon as the lower end of the discharging limb has been sealed by filling the weir chamber the falling stream of water gathers up and carries out with it a portion of the contained air, thus producing a slight rarefaction.

This rarefaction causes the water to rise in the intaking limb higher than in the basin outside, and hence increases the stream of water flowing over the mouth piece, which in turn increases the rarefaction, and the syphon is soon brought into full play.

On the tank being emptied to the bottom of the intaking limb the flow is checked, and the small syphon over the crest of

the weir draws the water from the weir chamber, air enters the discharging limb, and the syphon is vented ready for the tank to again fill.

Van Vranken's Flush-Tank.—This tank consists of an ordinary syphon, to the longer or descending limb of which is applied a small tilting tank. The arrangement of the parts is shown in Plate XIV. The tilting tank is hung directly below the descending limb of the syphon, at such a level as to leave its mouth sealed at all times. The tilting basin is contained in a small cast iron chamber, built into the bottom of the flush-tank chamber proper. The action of the tank is as follows:

The water being admitted to the tank by an ordinary faucet, at whatever rate may be desired, gradually rises in the tank until it overflows from the ascending to the descending leg of the syphon and is collected in the tilting tank. As it accumulates in the tilting tank the centre of gravity is thrown beyond the axis of support and the pan tilts over, assuming the position shown by the dotted lines, the water level in the basin being lowered about one inch. This produces a corresponding rarefaction in the syphon and brings it promptly into full action. When the tank ceases to discharge the tilting basin resumes its former position.

The Miller Automatic Flush-Tank.—As can be seen from the drawing, Plate XV, the syphon consists of a heavily trapped discharge pipe, with a large auxiliary syphon cast integral therewith, and of an annular intake-limb, or bell. The latter rests upon lugs, cast on the discharge pipe, and can be locked by turning it around for a short distance, after having been first put in position.

The discharging pipe of the Miller syphon projects about six inches into the bell, or about eight and one-half inches above the bottom of the lugs, the latter being most conveniently set on the floor of the cistern The discharge mouth of the trap, as can be seen from the drawing, projects freely a short distance above the bottom of the end of the syphon pipe. This provision is necessary to bring the syphon into action.

The operation is as follows: First, the trap is filled with water, and the bell put into position and locked, the water is then turned on. The air in the syphon is finally confined between the water of the trap and that of the tank. As the water in the latter rises above the bottom of the bell that of the trap recedes. The water of the tank will enter the bell in volume practically equal to the water forced out of the trap. Since the available sectional area of the bell is about five times as large as that of the syphon pipe, a depression of five inches in the trap will cause a rise of water in the bell of one inch. Thus, when the water is depressed in the trap to the lowest point, and a little beyond, the water in the bell stands about within one inch of the top of the discharge pipe.

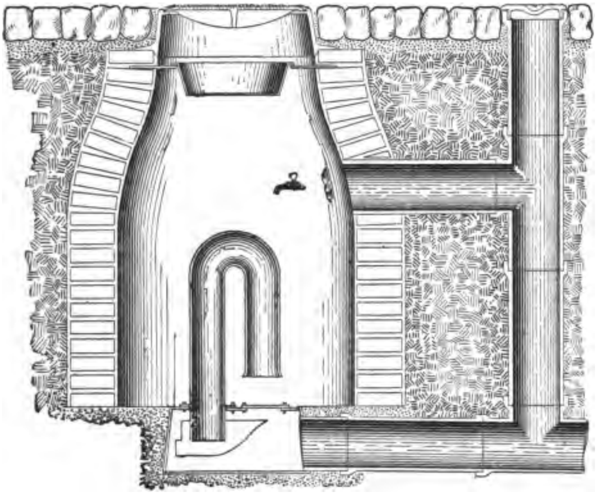
When the water is depressed in the trap somewhat beyond the lowest point, and around the bend, a large amount of air escapes at once through the vertical column of the water in the trap, throwing a portion of the water out into the sewer. The water in the tank and trap will at once hasten to supply the vacum thus created. Assuming that one-sixth of it will be supplied by the water in the trap and five-sixths by that in the bell, we will have a rise in the bell of less than one-half of an inch (still one-half of an inch below the top of the discharge pipe in the most favorable case) and a fall of water in the trap of one-third of an inch, without any other disturbance whatever, as the same tension of air that existed in the syphon before a portion of the air had made its escape, will have been restored. The water will now have to rise some again in the tank, so as to depress that in the trap once more beyond the lowest point, when another bubble of air will escape, with exactly the same result as as that first described, and so it will go on until the water flows finally over the top of the pipe in a trickling stream, the same in amount as supplied by the feed pipe, preventing any other action whatever. But if provision is made (as shown in the accompanying drawing, by the slight extension of the trap into the end of the syphon) for the expulsion of water from the trap by the escaping air, the syphon will be brought into action *immediately*.

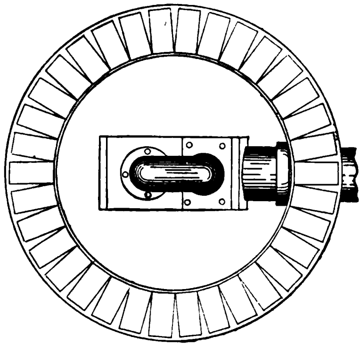
The reason for this is very obvious. When the water in the tank has sufficiently risen to depress that in the trap to the point at which the air is allowed to make its escape, it is just balanced by the column of water in the trap. If the escaping air now shortens this column suddenly, the larger column of water in the tank above is bound to overpower the shorter column in the trap. Thus, if two inches of water are thrown out of the latter the column of water in the tank will have to be shortened the same amount to be again held in equilibrium by that left in the trap, or in other words the water in the tank will have to fall practically two inches. Two inches of water, however, in a tank of four feet in diameter represent over 3600 cubic inches of water, enough to fill a five inch pipe of one hundred and eighty inches in length. These 3600 cubic inches will at once rush into the syphon. Being once filled the syphon will, of course, continue its action.

Rhoads-Williams Flush-Tank.—The Rhoads-Williams syphon, as illustrated, consists of an annular intaking limb, and a discharging limb terminating in a deep trap below the level of the sewer. Below the permanent water line in the discharging limb, is connected one end of a small blow-off or relief-trap, having a less depth of seal than the main trap, the other end of which joins the main trap on the opposite side, at its entrance to the sewer and above the water line of the trap. At the same point is connected an upright vent pipe which rises through the tank to a point above the high water line, and is turned down through the top of, and into the intaking limb of the syphon, terminating at a given point above its bottom.

As the tank fills with water (the main and blow-off traps being full) it rises in the intaking limb even with the level of the water in the tank until reaching the end of the vent pipe, a volume of air is confined in the two limbs of the syphon between the water in the intaking limb and the water in the main trap. As the water rises higher in the tank the confined volume of air is compressed and the water is depressed in the main trap and in the blow-off trap. This process goes on until the water in the

PLATE XIV.





VAN VRANKEN'S FLUSH TANK.

tank reaches its highest level above the top of the intaking limb, at which time the water is depressed in the blow-off trap to the lowest point and the confined air breaks through the seal, carrying the water with it out of the trap, thus releasing the confined air and allowing an inflow from the tank, putting the syphon into operation.

On the tank being discharged to the bottom of the intaking limb, the flow is checked and the syphon is vented by the admission of air to it through the vent pipe.

The Lightning Automatic Flush-Tank.—The operation of this flush-tank is as follows: See Plate XVII.

The water rises in the tank till it reaches the float "F" of the lever, it also rises under the air chamber, but owing to compression of the contained air the water will rise only to within one inch below the top of the inner leg at the time its outer level will have reached the centre of the float in the tank. The rising water acting on the float "F" then moves the lever "H" which holds down the hinged chamber "I." The instant the lever moves and releases the chamber the latter springs open on its hinges and the inner confined air bodily escapes. Gravity brings the chamber back to its original position immediately that the air has escaped, and full and complete syphonage takes place.

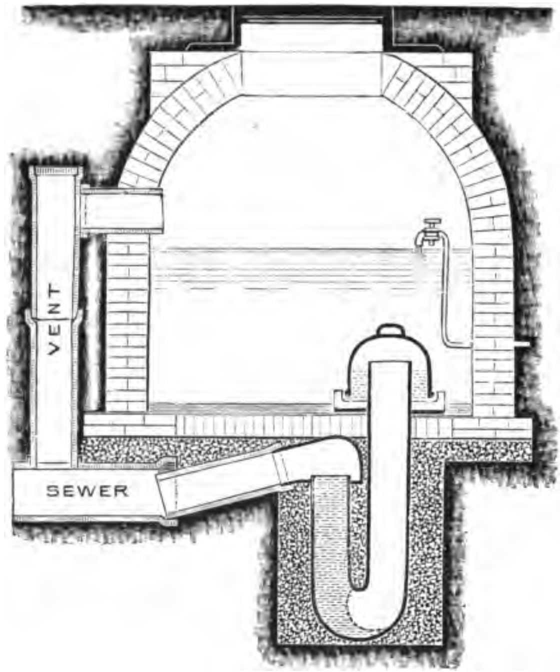
Valve Tanks.—In the valve tanks the valve is usually operated by a float which releases the valve when the water has reached a certain level.

Requirements to be Met.—The requisites for an automatic flush-tank are: 1, Certainty of action; 2, rapidity of discharge; 3, simplicity of construction; 4, ease of inspection of all of its parts; 5, durability; 6, economy of cost and maintenance.

Strange as it may appear, there are flush-tank syphons, sold in considerable numbers, which cannot possibly be made to work under the usual conditions imposed by the requirements for flushing sewers.

Rapidity of discharge is next in importance to certainty of action. The sewer pipe should be filled for some distance in order to get the proper benefit from the flush.

PLATE XV.



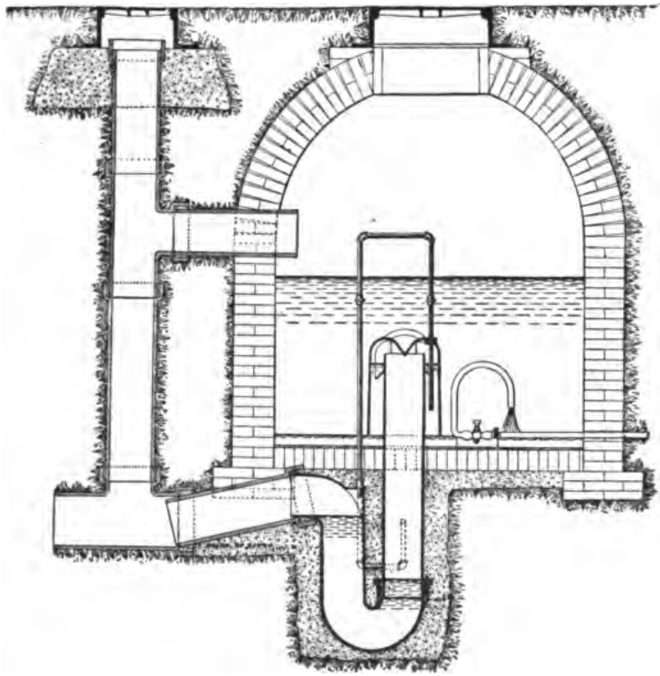
THE MILLER AUTOMATIC FLUSH-TANK.

In simplicity of construction the syphon tanks are superior to the valve tanks, and as durability is likely to depend upon simplicity of construction, the syphon tanks will, in general, be most durable.

Complicated mechanism is undesirable for use in a flush-tank, which must work automatically, and often for a long time without inspection. It is not at all uncommon to find that devices which look well on paper fail utterly when put to the test of actual service.

Quantity of Water Required.—An erroneous idea prevails as to the quantity of water required for flushing sewers by the use of automatic flush tanks. A properly designed system for a city of 10,000 inhabitants ordinarily requires from twenty

PLATE XVI.



RHOADS-WILLIAMS FLUSH-TANK.

to fifty flush-tanks, each of a capacity of about 150 gallons, discharging daily, or at most twice a day. The maximum amount of water required is about two per cent. of the water supply. This momentary discharge does not sensibly occupy the capacity of the main sewers further down the line, being, as before stated, but a very small percentage of the ultimate discharge. An equally efficient flushing by a constant stream, applied directly and without the intervention of a flush-tank, would require an amount of water materially encroaching upon the capacity of the main sewers, and would be inadmissible under ordinary conditions of water supply, on the score of economy.

Rapidity of Discharge.—Flush-tanks are ordinarily constructed of about from 125 to 250 gallons capacity and adjusted

to discharge automatically once or twice in each twenty-four hours. Their capacity of discharge should equal that of the pipe into which they empty.

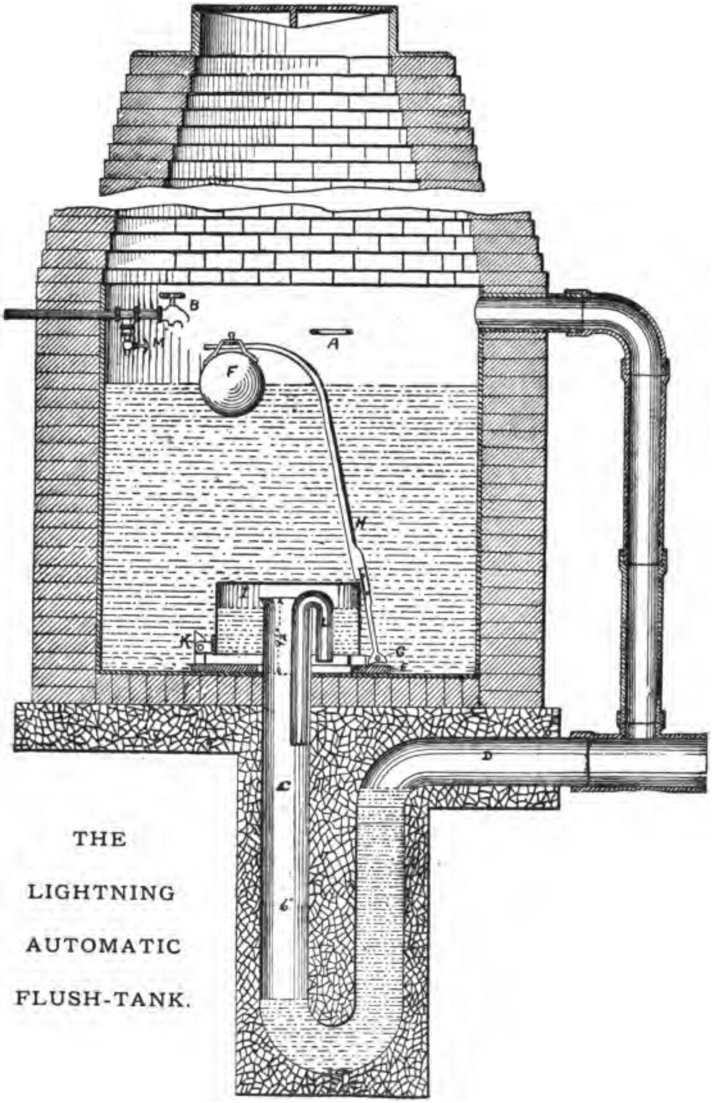
Experiments made by the writer with a flush-tank of 7,000 gallons capacity, having a ten-inch outlet, opening into an eight-inch sewer, demonstrated that with the minimum grades indicated in Table XIII, there was no danger of gorging the sewer at a distance of one or two hundred feet from the flush-tank, although the hydraulic head was seven feet. At a distance of 600 feet the flow, as observed in a man-hole, did not fill the sewer.

In the case of flush-tanks as ordinarily constructed—say 125 gallons capacity, three feet hydraulic head, tributary to a six-inch sewer—the tank can hardly discharge too rapidly.

The rate of discharge from the tank should at least equal the capacity of the sewer when the flow has acquired the velocity due to its inclination. A sewer six inches in diameter, laid at a grade of five-tenths per hundred, discharges, when full, at the rate of 215 gallons per minute. The conditions above named would therefore require the 125 gallons to be discharged in thirty-five seconds.

In the case of the large tank above given, the contents of the tank would be contained in 2,682 feet of the sewer, while in the ordinary case cited the contents of the tank would be contained in eighty-five feet of the sewer.

PLATE XVII.



THE LIGHTNING AUTOMATIC FLUSH-TANK.

CHAPTER XI.

HOUSE DRAINAGE AND PLUMBING.

House Connections.—In order to protect the sewers from injury by careless or incompetent workmen, or from stoppage by the introduction of improper substances into the sewers, proper rules and regulations for house drains and connections are necessary.

To permit each householder to connect with the sewers whatever he chooses, wherever he chooses and in whatever way he chooses, is to insure ruin to the whole system. The house drains should be connected only at the Y's, which have been placed in position when constructing the sewers.

All work should be done by competent workmen, who are under bonds to do the work properly and repair all damage they may do, and under the direction of a trustworthy engineer or inspector.

Care must be taken to exclude everything which will be liable to obstruct the sewers. The man who said that he thought "the sewers should carry potato peelings and such things" is not alone in his notions regarding the disposal of garbage. A large majority of the domestics employed in families have unlimited faith in the capacity of waste pipes and sewers to carry empty cans, broken bottles, ashes, cinders, wash cloths, etc. This confidence in the carrying power of a pipe is so firm that it will be found easier to render the introduction of miscellaneous articles impossible than to demonstrate that the transportation qualities of a sewer are limited. It will be much better to prevent improper things being introduced into the sewers than to be obliged to dig up the pipes to remove obstructions. The sewers are intended to carry only fluid refuse from kitchens, laundries,

water closets, bath-tubs, slop sinks, etc., and care must be taken to exclude all solids, cloths, mud and anything which would be liable to obstruct the flow in the pipes.

The house drains will be much more likely to get into bad condition than the public sewers, and hence the necessity for great care in laying the drain and in providing for its ventilation and flushing.

Municipal Control.—It will be found best to pass a general ordinance governing the use of sewers by private individuals.

The following forms though not universally applicable may be useful as guides in outlining work of this kind.

ORDINANCE.

An Ordinance Fixing and Regulating the Use of Sewers by Private Individuals in the City of..

Section 1. The Sanitary Sewer system of the city of........... ...... consists of..........

Main and lateral conduits of salt-glazed, vitrified earthenware or brick, with necessary accessories. They are designed to carry off all liquid house wastes, and are known herein as sanitary sewers. The sewers in the streets passing in front of the various lots are called main or lateral sewers. The sewers leading from the main or lateral sewers to the property on either side are called house sewers. Porous drains laid for removing subsurface water are called subsoil drains.

CONNECTIONS.

Sec. 2. All connections of house sewers, drains or plumbing work with the sewer system of the city of.............shall be made in accordance with these rules and regulations.

LICENSED PLUMBERS.

Sec. 3. No person, firm or corporation shall lay alter or repair any house-drain, sewer or plumbing work or make any connections whatever with any sewer or drain belonging to the sanitary sewer system, or do any kind of work connected with the laying of house-drains or house-sewers or plumbing or making any repairs, additions to or alterations of any drain, sewer or plumbing connected, or designed to be connected with the sanitary sewer system, unless regularly licensed by the.... ....

APPLICATION FOR LICENSE.

SEC. 4. Any person desiring to do business as a plumber, in connection with the sanitary sewer system, shall file in the office of the. . ... a petition giving the name of the individual or firm and place of business, and asking to be licensed as a plumber. Said petition must be signed by two responsible citizens, of the city of............................., vouching for the business capacity and reputation of the applicant—that he is a resident of ...., a *master* of his trade, and willing to be governed in all respects by the rules and regulations which are or may be adopted by the............... Each applicant for a license shall execute and deposit in the office of the................., with his application, a bond with two or more resident sureties, to be approved by said ...., in the sun of ...., conditioned that he will indemnify and save harmless the city of.................from all accidents and damages caused by any negligence in protecting his work, or by any unfaithful, imperfect or inadequate work done by virtue of his license, and that he will also replace and restore sidewalk, pavement or street surface over *any* opening he may have made to as good state and condition as he found it, and keep and maintain the same in good order, to the satisfaction of the ...., for the period of six months next thereafter, and that he will pay all fines imposed upon him for a violation of any of these rules or regulations. On receiving his license he shall have recorded in the office of the ....his actual place of business, the name under which the business is transacted, and shall immediately notify the...............of any change in either thereafter. No license will be granted for more than one year and all licenses will be granted to expire on the......day of............ Removal of residence from the city shall act as a forfeiture of license.

PERMITS.

SEC. 5. Applications for permits to connect with the sewer system or do plumbing work to be connected therewith, must be made in writing by the owner of the property to be drained or his authorized agent. Such application shall give the precise location of the property, the name of the owner and the name of the person employed to do the work, and shall be made on blanks furnished for the purpose. No permit shall be deemed to authorize anything not stated in the application, and for any misrepresentation in such application the plumber shall be suspended; and if such misrepresentation appears to be wilful his license shall be revoked.

Permits to make connection with the sewer system will be issued only when the plumbing in the house or building to be connected is in accordance with the rules for plumbing hereinafter prescribed and has been inspected and approved by the Superintendent of Sewers, or in case of new buildings.

when a proper plan for the plumbing has been approved by the Superintendent.

The Superintendent will designate the position of the "Y" branch in the street, as shown by the records in the......................office. All connections made with the sanitary sewers or drains and all plumbing connecting therewith shall be made under the direction of the Superintendent of Sewers.

PLAN OF PLUMBING.

SEC. 6. Before a permit will be issued for doing plumbing work in a building, or before any additions are made, excepting necessary repairs, a plan and description of the work to be done signed by a licensed plumber on blanks furnished for the purpose shall be filed in the office of the sewer department, and no such work shall be commenced until such plan shall have been approved by the Superintendent.

Every plan shall contain a clear and full description of the plumbing, showing the position, size, kind and weight of all pipes, and the position and kind of traps, closets and other fixtures. All work done under such plans shall be subject to the inspection of the Superintendent, and no alteration shall be made in any plan or in the work without a special permit in writing from him.

INSPECTION.

SEC. 7. The Superintendent is to be given notice when any work is ready for inspection, and all work must be left uncovered and convenient for examination until inspected and approved. Such inspection shall be made within twenty-four hours after such notification. The Superintendent may apply the ether, peppermint, water or smoke test, and the plumber shall furnish all necessary tools, labor and assistants for such tests. The plumber shall remove or repair any defective material or labor when so ordered by the Superintendent.

STATEMENT OF WORK DONE.

SEC. 8. The plumber shall, on the completion of the work, file in the office of the Sewer Department, on blanks furnished for the purpose, a correct statement of the work done under the permit.

CESS-POOLS—OVER-FLOWS.

SEC. 9. No open gutter, cess-pool or privy vault shall be connected with any sewer or drain. Cellar and cistern over-flows may be connected with the sewer or drain only when they can be trapped in such a manner that the water seal cannot be destroyed.

INJURY TO SEWERS.

SEC. 10. No person, firm or corporation shall injure, break or remove any portion of any man-hole, lamp-hole, flush-tank, catch-basin or any part of

the sewer system, or throw or deposit, or cause to be thrown or deposited in any sewer opening or receptacle connecting with the sewer system, any garbage, offal, dead animals, vegetable parings, ashes, cinders, rags or any other matter or thing whatsoever, except fæces, urine, the necessary water-closet paper, liquid house or mill slops and roof water by special permit.

WATER AND GAS PIPE.

SEC. 11. Any person, firm or corporation desiring to lay pipes for water, gas, steam, or any purpose, in any street or alley upon which sewers are laid, shall give at least twenty-four hours' notice to the Superintendent before opening the street, and the manner of excavating, for laying and back-filling over such pipe shall be subject to the approval of the Superintendent. All such work shall be planned and executed so that no injury shall occur to any public sewer or drain or to any house sewer or drain connected therewith.

OBSTRUCTIONS.

SEC. 12. The Superintendent shall have the power to stop and prevent from discharging into the sewer system any private sewer or drain through which substances are discharged which are liable to injure the sewers or obstruct the flow of the sewage.

SEC. 13. Before any old private drain or sewer shall be connected with the sewer system, the owner of the private drain or sewer shall prove to the satisfaction of the Superintendent that it is clean and conforms in every respect with these rules and regulations.

TRENCHING.

SEC. 14. The house sewer trench shall be dug so as to meet the public sewer at the position of the "Y" branch, as located by the Superintendent. The material thrown from the trench shall be placed so as not to obstruct and so as to cause the least inconvenience to the public. Proper barriers and lights must be maintained on the banks of the trench to guard the public against accidents during the progress of the work. In back-filling the earth shall be carefully rammed or flooded so as to keep the pipe in proper position and avoid settling, and no stone shall be used in filling until there has been a depth of two feet of fine earth or gravel placed over the pipe.

MATERIAL FOR SEWERS AND DRAINS.

SEC. 15. The house sewer, from a point three feet outside of the house to the street sewer, shall be of first quality, salt-glazed, vitrified earthenware pipe, unless laid less than three feet deep, when it shall be of heavy cast or wrought iron. Its interior diameter shall be...... .... inches. Outside the curb line it shall be............inches. Subsoil drains shall be of earthenware pipes.

PIPE LAYING.

SEC. 16. The cover of the "Y" branch on the sewer shall be carefully removed, so as not to injure the socket. The first length of pipe attached to the "Y" branch shall be curved and set so as to give a good fall into the sewer.

The pipe shall be laid on an even grade of not less than one-fourth of an inch to the foot, unless by special permission of the Superintendent, in which case provision must be made for regular and efficient flushing.

Curved pipe shall be used for every deflection from a straight line of more than six inches in two feet.

The joints of the earthenware pipe shall be made with the proper oakum or jute gasket, and pure cement of first quality; the joints of the iron pipe shall be of oakum and lead if cast-iron is used, or screwed joints with white lead if wrought iron is used.

The ends of all private sewers not immediately connected with the plumbing fixtures shall be securely closed by water-tight imperishable material. If lead pipe, the end must be soldered; if wrought iron pipe, a plug must be screwed in the end; if cast-iron pipe, a cast-iron plug must be calked in with the lead.

Cellars shall be drained, when possible, by means of suitable, properly laid earthenware tile pipes. They shall not communicate directly with any drain carrying foul sewage, or with a sewer or cess-pool. Where possible they shall connect with the sub-soil drains in the street.

PLUMBING RULES.

SEC. 17. All materials used must be of good quality and free from defects; the work must be executed in a thorough and workmanlike manner.

From a point three feet outside the foundation walls of a building no material may be used within the building and connecting with the sewer, for soil, waste, or vent pipes, other than wrought or cast-iron pipes, with securely leaded joints, or lead pipes with soldered or wiped joints. Cement or putty joints, tin or sheet-iron pipes, whether galvanized or not, shall not be used.

No soil or waste pipe shall have a fall of less than one inch in ten feet.

PIPES.

SEC. 18. All cast-iron pipes must be sound, free from holes or cracks, and of the grade known in commerce as extra heavy, coated with tar or asphaltum. The following weights per lineal foot will be accepted as standards:

2 inches	5½ pounds per lineal foot.
3 inches	9½ pounds per lineal foot.
4 inches	13 pounds per lineal foot.
5 inches	17 pounds per lineal foot.
6 inches	20 pounds per lineal foot.

All wrought iron pipe must be of standard weight.

All fittings used in connection with such pipe shall correspond with it in weight and quality. Where lead pipe is used to connect fixtures with vertical soil or waste-pipes, or to connect traps with vertical vent pipes, it must not be lighter than "light-pipe."

The arrangement of soil and waste-pipes must be as direct as possible. The drain, soil and waste-pipes and traps should, if practicable, be exposed to view at all times, for ready inspection and for convenience of repairing. When necessarily placed within partitions or in recesses of walls, soil and waste pipes should be covered with wood-work so fastened with screws as to be readily removed.

MAIN, SOIL AND WASTE-PIPES.

SEC. 19. A main waste-pipe into which wash-basins, bath-tubs or kitchen sinks discharge must be at least two inches in diameter, with one and one-half inch branches.

The main pipe from the sewer connection to the house tap must be at least four (4) inches in interior diameter at every point. No trap or any manner of obstruction to the free flow of air through the whole course of the main house-sewer or soil pipe will be allowed.

This may be secured by an untrapped main house sewer and soil-pipe, or if a trap is placed in the main soil-pipe, by a ventilating pipe leading to the roof from the lower side of the trap and a fresh air inlet connecting with the foot of the main soil-pipe just above the trap.

Every vertical, soil and waste-pipe must be extended at least two feet above the highest part of the roof or coping. It must be of undiminished size, without return bend, with open or basket end. It must not open near a window nor an air shaft which ventilates living rooms.

Soil, waste and vent-pipes in an extension must be extended above the roof of the main building, when otherwise they would open within twenty feet of the windows of main house or the adjoining house.

JOINTS.

SEC. 20. All joints in iron drain-pipes, soil-pipes and waste-pipes, except where screw joints are used, must be so filled with oakum and lead and hand-calked as to make them gas tight.

All connections of lead pipes with iron pipes must be made with a brass or lead sleeve or ferrule of the same size as the lead pipe, put in the hub of the branch of the iron pipe and calked with lead. The lead pipe must be attached to the ferrule by a wiped or over-cast joint.

All connections of lead, waste and vent pipes shall be made by means of wiped joints.

INSPECTION.

SEC. 21. Before the fixtures are placed in connection with the plumbing of any house or building, and before the soil-pipe is connected with the sewer, the out-let of the soil-pipe and all openings into it below the top, shall be hermetically sealed; the pipe shall then be filled with water to its top, and every joint be carefully examined for leaks. Work already in place will be examined by the peppermint or other test. Defective pipes discovered must be removed and replaced by sound ones, and all defective joints made tight, and every part of the work be made to conform to these rules and regulations, and subject to the approval of the Inspector.

In cases where plumbing work has been completed in a building before these rules and regulations came in force, if the plumbing has been done in accordance with these rules and regulations, permits will be granted for making connections with the sewer as in new work, but in case the plumbing is not in accordance with these rules and regulations, such alterations shall be made as the Superintendent shall direct, to make the plumbing safe to the persons residing in the house, and such as to be no source of injury or stoppage to the sewer. In all cases the soil pipe shall pass through and above the roof. Traps are to be ventilated, fixtures and pipes clean, and waste and soil-pipes to have sufficient fall.

TRAPS.

SEC. 22. Every water-closet, urinal, sink, wash-tray, bath-tub, and every tub or set of tubs must be separately and effectually trapped. Traps must be placed as near the fixtures as practicable. In no case shall water from bath-tub or other fixture be connected with the water-closet trap.

Sinks in all packing-houses, butcher-shops, lard-rendering establishments, hotels, restaurants, boarding-houses and laundries shall be provided with a suitable grease trap. Wash-rooms for carriages must be provided with proper means for intercepting mud.

VENT-PIPES.

SEC. 23. Traps must be protected from syphonage, or the waste pipe leading from them ventilated by a special air pipe, taken out of the crown of trap, in no case less than two inches in diameter for water-closet traps, and one inch and a quarter for other traps, except when more than fifteen feet in length, when it shall not be less than one and a half inches in diameter. The vertical vent-pipes for traps of water-closets in buildings more than four stories in height, must be at least three inches in diameter, with two-inch branches to each trap, and for traps of other fixtures not less than two inches in diameter, unless the trap is smaller, in which case the diameter of branch vent-pipe must be at least equal to the diameter of the trap. In all cases vent-pipes must be of cast or wrought iron and connected to traps with brass or lead ferrule.

Vent-pipes must extend two feet above the highest part of the roof or coping. The extension to be not less than three inches in diameter to avoid obstruction from frost, or they may be branched into a soil-pipe above the inlet from the highest fixture. They may be combined by branching together those which serve several traps. These air pipes must always have a continuous slope to avoid collecting water by condensation.

No trap vent-pipe shall be used as a waste or soil-pipe.

No brick, sheet metal, earthenware or chimney flue shall be used as a sewer ventilator, nor to ventilate any trap, drain, soil or waste-pipe.

SAFES—RAIN WATER.

SEC. 24. Every lead safe under a wash-tray, urinal, refrigerator or water closet must be drained by a special pipe not directly connected with any waste-pipe, soil-pipe or sewer. The drip pipe from refrigerators shall not be connected directly with the soil or waste-pipe or with the sewer.

Rain water conductors shall not be connected with the sewers without a special permit.

OVERFLOWS FROM FIXTURES.

SEC. 25. Overflows from fixtures must, in each case, be connected on the inlet side of the trap.

WATER-CLOSETS.

SEC. 26. Water-closets must be of an approved pattern (pan closets being absolutely prohibited), and should be supplied from a special tank placed over them, in which case the waste or overflow from the tank must discharge into the open air of the basin of the closet, and not into the soil-pipe directly. Direct service of a water-closet is prohibited.

All interior water-closet compartments should be ventilated into air shafts where possible.

STRAINERS.

SEC. 27. Exit-pipes to all fixtures except water-closets shall be furnished with suitable permanently attached strainers.

SEC. 28. No person shall place, or suffer to be placed, any bulky substance in any sewer opening, or in the house connections, or private drains connecting with any public, main or lateral sewer, or any substance having a tendency to obstruct the free flowage of said sewers or to damage them in any way.

PENALTY.

SEC. 29. Any person violating any of the provisions of these rules and regulations shall de deemed guilty of a misdemeanor, and upon conviction

thereof be fined in any sum not exceeding fifty dollars nor less than ten dollars, or imprisonment in the.................for a period not exceeding twenty days or by both such fine and imprisonment, at the discretion of the court.

PLUMBER'S LICENSE.

CITY OF.... ...., SEWER DEPARTMENT.

No........... ....189..

....hereby licensed to do plumbing and lay house sewers and drains in connection with the public sewers in this city in accordance with the provisions of an "Ordinance No........., fixing and regulating the use of sewers by private individuals in the City of ...."

....

Sewer......................

PLUMBER'S BOND.

Know all Men by these Presents, that we,............................. of the City of................., as principal, and........................ and......................., as sureties, are held and firmly bound unto the City of............. .. ..in the penal sum of...........Dollars to be paid to the said, the City of.............., or to its certain attorney, successors or assigns.

For which Payment well and truly to be made, we bind ourselves and our heirs, executors and administrators, jointly and severally, firmly by these presents.

Sealed this................day of...............in the year of our Lord one thousand eight hundred and eighty-.............

Whereas, The said party of the first part has made application to be licensed to engage in the business of plumbing in connection with the public sewers of said city, which license has been granted, conditioned upon the execution of this bond, as provided by Ordinance No....... ..of the Common Council of said city, passed....................

Now, therefore the Condition of this Obligation is such, That if the said party of the first part shall well and faithfully, and in a workmanlike manner perform the work of connecting such sewers, and shall save and indemnify the party of the second part of and from all costs, damages and expenses arising

from making such connections, or the negligence or carelessness of the party of the first part, his agents, servants or employees in making the same, then this obligation to be void, otherwise to remain in full force and virtue.

Sealed and delivered in the presence of

....

....

....

OWNER'S APPLICATION.

To the Department of Sewers,............................

Please deliver to...... ...., a licensed plumber, permit for a connection with the...............Sewer on.............Street, for premises No. .... Street. I authorize him to sign for me such an application for the same as is required by the regulations of said Department.

....Owner.

..........................189..

APPLICATION FOR PLUMBING.

To the Department of Sewers,.... ....

No............ ....189..

The undersigned applies for permission to connect premises No.......... ....Street, with the public sewer in................... Street, and to do the necessary plumbing, and I hereby desire a permit to be issued to........................., a regularly authorized and licensed plumber.

I hereby stipulate and agree that the work on said sewer shall be executed in strict conformity with the provisions of "An ordinance fixing and regulating the use of sewers by private individuals in the............... ....," and the plans and specifications approved by the Superintendent of Sewers in .... And the undersigned further agrees that all claims against the City of.................for damages occasioned in any manner by the putting in of said sewer shall be waived, and held null and void.

.........................Owner.

PERMIT TO CONSTRUCT SEWER.

No............ ....189..

Authority is hereby given to ....

..........................to execute the work for......................

upon the terms and conditions specified in above application.

....

....

No dwelling of any pretensions is now considered complete or even looked upon with favor by a prospective tenant, unless it is fitted with "modern conveniences." These appliances are entirely proper and safe if the work is entrusted to proper hands. It is hard to conceive of a class of work, however, in which wrong methods or poor work are more detrimental, or the resulting influences more insidious.

House Drainage.—House drainage in its broader sense means both the removal of the liquid waste and whatever it carries with it, and also the removal of the subsoil water and storm water. Indeed, what is often spoken of as house drainage is strictly house sewerage. House drainage is the removal of ground water.

The Subsoil.—The principal distinction between a sewer and a drain is that the former, being for the conveyance of foul liquid, should be absolutely tight, so that none of the contents may be lost by the way, and no vapors escape. A drain, on the contrary (as for instance a subsoil drain), must be laid with open joints, so that, the pressure being from without, it will receive the ground water all along its course, and remove it. The functions of the two are distinct. When both kinds of drainage are necessary, it is best to keep each system distinct. When a general system of sewerage is already constructed without regard to subsoil drainage, the householder frequently has no option but to connect the drainage system with the sewer proper. A very good method in such a case is to make the connection through the medium of a deep seal trap where the street sewer enters the house. This connection should be through an iron pipe, properly calked into the trap, and provided with a brass-seated check

valve which will prevent the sewage from filling the subsoil drains in case the street sewer becomes obstructed. The subsoil drains should be of small agricultural tile laid well below the cellar bottom, and the joints properly protected. The sides and bottom of the cellar or basement should be thoroughly damp-proof. We are aware that this point is generally overlooked. We do not stop to consider that the earth below and about buildings is a great collector and retainer of filth, and that it is sufficiently porous to admit of the passage of air currents in considerable volume, especially under the influence of furnace draughts or other like causes. The action is not unlike what would occur if we suppose the house to be set on a sponge 50 x 100 feet, for instance, to which we constantly apply a stream of foul liquid, and then induce upward currents through the house by the action of heat. The cellar walls and floor can be very easily and cheaply made damp-proof and air-tight by a coating of some preparation of asphalt.

House Sewers.—One of the most common blunders in house drainage is in making the house sewer too large. It is very rare that any house will require a house drain (i. e. the pipe which carries the sewage from the house to the public sewers) more than four inches in diameter, and yet it is not uncommon to find a private house provided with a drain large enough to carry the sewage of a town of five thousand inhabitants. This use of unnecessarily large pipe arises from two causes. The ignorance of the owner, who not knowing what is required, determines "to have it big enough, any way," and the cupidity of the plumber, who favors any plan which swells the amount of his bill. Any unnecessary addition to the size of a house drain not only causes needless expense, but renders it more difficult to flush the drain and keep it clean. This point has been fully discussed in Chapter VI.

The practice of placing the house drain beneath the cellar floor is very objectionable for two reasons: It is out of sight and cannot easily be inspected, and it is usually laid on too flat a grade, especially when it runs beneath the floor for a consider-

able distance. The pipe should be placed along the cellar wall, or hung from the floor beams, so that it can be readily inspected, and can be given a proper grade to secure a sufficiently rapid flow of the sewage. T branches with tight covers, placed along the pipe will afford the means of inspecting the interior of the drain and removing obstructions.

The house drain within the house should never be of earthenware. It should be of iron, and heavy enough to admit of having the lead joints calked so as to be water and gas tight

If roof water is admitted directly to the sewers, the rain-water leader should connect with the main soil pipe directly above the main trap. No waste or soil pipe should be connected with the rain-water leader. In a great many cases it will be advisable not to discharge the roof water into the sewers, particularly in the case of isolated dwellings where a portion of it is retained by cisterns, and where lawns are of considerable extent. In the case of more compactly built city buildings it will often be best to allow the roof water to be discharged into the street gutters, especially where these are properly arranged, and the descent is sufficient.

The following table of the behavior of house drains when running three-fourths full was calculated by Robert Moore, C. E., of St. Louis, Mo.:—

TABLE XX.

TABLE OF DIAMETERS OF HOUSE DRAINS.

With various grades, and for lots of different sizes, capable of discharging two inches of rain per hour, when running three-fourths full.

Calculated by Robert Moore, C. E., St Louis, Mo.

SIZE OF LOT IN FEET.	FALL PER 100.						
	1.0	1.5	2.0	2.5	3.0	4.0	5.0
	DIAMETERS IN INCHES.						
20x150	3½	3⅛	3	2⅞	2¾	2⅝	2½
25x150	3¾	3½	3¼	3⅛	3	2⅞	2¾
30x150	4	3¾	3½	3⅜	3¼	3	3
35x150	4¼	4	3¾	3⅝	3½	3¼	3⅛
40x150	4½	4¼	3⅞	3¾	3⅝	3½	3¼
45x150	4¾	4⅜	4⅛	4	3⅞	3⅝	3½
50x150	5	4½	4¼	4⅛	4	3¾	3⅝
60x150	5⅜	5⅞	4⅝	4⅜	4¼	4	3⅞
70x150	5⅝	5¼	4⅞	4¾	4½	4¼	4⅛
80x150	6	5½	5¼	5	4⅞	4½	4⅜
90x150	6¼	5¾	5½	5¼	5	4¾	4½
100x150	6½	6	5¾	5½	5¼	5	4¾

By an inspection of the Table, we see that a four inch main house sewer is ample for any ordinary condition of service, even if roof water be admitted, the discharge of house sewage proper being only a very small percentage of the total volume. A smaller size than four inches is not to be recommended, however, for the reason that although it may be ample so far as estimated carrying capacity is concerned, it is more liable to obstruction. Under some circumstances it may be advisable to increase the size of the main drain to five or even six inches diameter, this limit should not be exceeded however. If one drain of this size is not ample it is better to increase the number.

In order to provide for ventilating the house drain it should be carried full size up through the roof. This ventilation of house drains has been discussed in a previous chapter.

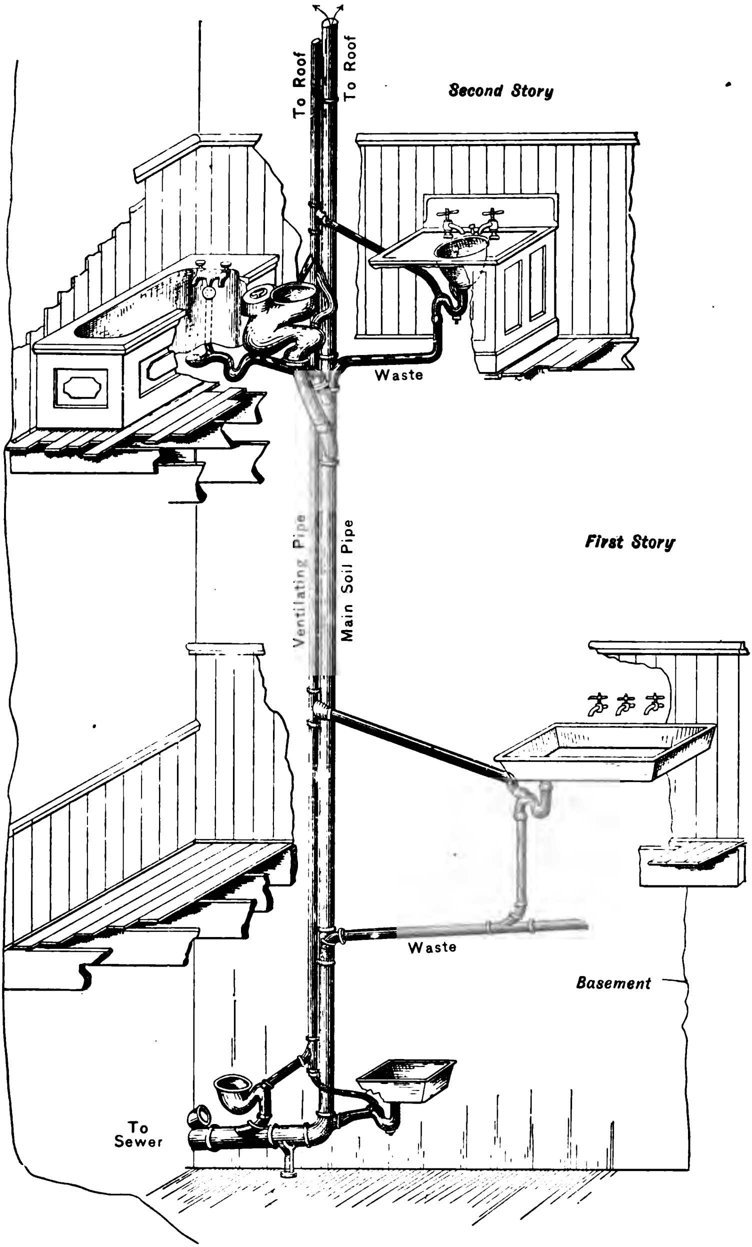
Grease Traps.—The principal danger of stoppages in a house drain, properly laid, arises from the grease carried into it from the kitchen sink. This can be avoided by the use of a grease trap, placed under the sink. The objection to the use of a grease trap is that they need to be cleaned occasionally, and if not cleaned they get very foul.

Soil and Waste Pipes.—Soil pipes, that is, pipes leading from water closets, and waste pipes, that is, pipes leading from bath-tubs, wash stands, etc., may be either of iron or lead. Iron is the better material where it can be used, but lead is easier to fit and adjust where the connection between the fixture and the main drain is not direct. All iron pipes should be either enameled or coated inside and out with coal pitch varnish to give them a smooth surface and keep them from rusting. All junctions and changes in the direction of the pipe should be made by easy curves.

A very common fault is to make the upward extension of the soil pipe after it passes the highest fixture, of galvanized sheet iron, or even of tin. This is highly objectionable. It should be of heavy iron pipe throughout, and should extend well above the roof. It is a good plan to increase it in size above the roof to six inches, so as to lessen the danger of its being obstructed by the accumulation of frost. Ventilating cowls are of doubtful utility. A plain wire basket to prevent the introduction of articles liable to obstruct the pipes is better.

There is such a variety of branches, curves, off-sets, traps, etc., etc., now in the market, that there is no excuse for awkward and rough connections and interior projecting angles or pockets which will retain the solid portion of the sewage. The course of all pipes should be as direct as possible, and the fixtures should be grouped so as to be reached as nearly as possible by upright soil pipes and short horizontal soil or waste pipes. Horizontal pipes cannot be carried any great distance along floors or ceilings or between joists, and preserve a proper inclination, for reasons which are obvious. It is customary to make waste pipes, particularly short ones, of lead, for the reason that it is

PLATE XVIII.



INTERIOR PLUMBING.

much more easily manipulated than iron. The proper method of connecting the lead wastes to iron is by means of a thimble soldered to the lead pipe and calked into a hub on the iron pipe.

Traps and Ventilation.—Every fixture should be provided with a trap, and since the object of the trap is to isolate the fouled interior surface of the waste pipe from the air of the room it is evident that the trap should be as close to the fixture as possible. Notwithstanding many efforts to introduce a trap whose seal cannot be broken by syphonage, and which will be self-cleansing, the plain-running trap of uniform bore is still in general use. This trap is liable to have its seal broken by syphonage, and to prevent this it is necessary to resort to a back air pipe, which is connected with the crown of the trap on the downward side, and passes to the roof independently of the ventilating pipe proper, or is connected with it above the highest fixture. This back air pipe should be of ample capacity to preserve the equilibrium of air pressure.

The system of back air vents is open to the following objections: It considerably complicates the system of piping, especially where fixtures are not closely grouped. There is a possibility of the pipes being fouled at their junction with the crown of the trap. It adds considerably to the expense.

Back air vents tend to increase the interior circulation of air considerably. This is beneficial, so far as purity of the interior of the pipes is concerned, but it also increases the evaporation from traps. This will do no harm if fixtures are in constant use. On the other hand, if special anti-syphoning traps are used, and back vents are dispensed with, there will be little circulation of purifying outer air through the waste pipes.

Flushing.—An automatic flushing tank, holding about twenty gallons, and adjusted so as to flush the drain pipes once or more every day, should be placed above the highest fixture in the house. By thus providing for thoroughly cleansing and ventilating the pipes, the danger from sewer gas is reduced to a minimum.

General Features.—Corners and recesses within the pipes and plumbing fixtures should be avoided. All interior surfaces should be thoroughly flushed at every rush of water through the pipes, otherwise the animal matter left sticking to the surface will decompose and send off foul gases. On this account the use of "pan closets," and many patterns of traps, should be discontinued. The plumbing fixtures in a house should be as few as possible. Not only is every additional fixture and pipe joint a possible source of danger, but the principal danger from sewer gas arises from rarely used fixtures, from which the water in the traps has evaporated.

The fixtures on the different floors should be arranged so as to have them as nearly in a vertical line as possible, in order to avoid running waste and soil pipes horizontally or with insufficient fall.

The less wood-work around fixtures the better. Not only does the wood itself become foul, but the space within the casing is dark, damp and dirty—a favorable locality for mould and rot, and a breeding place for vermin.

Unwholesome smells, which are attributed to some faulty construction or arrangement in the drainage pipes, often have their origin in these inclosed spaces.

It is not uncommon in summer, when the air is loaded with moisture, to see water accumulate in bead-like drops on the surface of plumbing fixtures or pipes which are kept cool by a current of water from a tap, and course downward almost in streams. If the fixtures are not inclosed they can be readily wiped dry. If inclosed they receive no attention, and the accumulation of dirt and moisture becomes very offensive.

The better kinds of water closets are made so as to require no wood surrounding them, except a cover. A very good way to fit up wash stands is to support the slab upon brackets fastened to the wall, leaving the under side entirely open, and the pipes, traps, etc., entirely exposed, or partially hid by a narrow slab placed edgewise under the shelf proper, and extending downward about six inches.

So far as possible it is preferable to have soil, waste and ventilating pipes exposed, to having them inclosed within partitions where they are inaccessible either for inspection or repair.

This method of arrangement is not without its influence on the plumber. He is not less inclined to pour lead joints properly, or to thoroughly calk them all around, or to make neat and perfect wiped joints, than when he knows that the carpenter or plasterer will cover his work within a few hours. The average house owner will look upon this arrangement as decidedly lacking in finish and not in harmony with interior decorations. Neither is a stove pipe, a furnace register, a steam radiator, or a gas fixture. This is largely a matter of education, and possibly we have been wrongly taught. It is not customary, however, to place these fixtures in rooms where any exceptions can be taken to this method of arrangement.

The common practice of placing water closets and other plumbing fixtures in dark ill-ventilated places, such as inside rooms, dark closets, under stairways, etc., is wrong in every way. All plumbing fixtures and pipes should as far as possible, be kept open to the air and light. The places which are naturally the most foul stand most in need of sunlight and pure air.

Where it is possible to avoid it, no plumbing fixtures should be placed in a bedroom. During the night some decomposition will be going on above the trap in any fixture, and some foul gas will be given off. This, with the chance of sewer gas coming in through some defective joint, pipe or trap makes the risk too great to be taken if it can be avoided. They should be confined to the bath-room, where special means of ventilation can be employed, and to the kitchen laundry and similar rooms.

A multiplicity of fixtures should be discouraged. A fixture rarely used is a greater source of danger than one used frequently.

Particular care should be used in arranging the ventilation of a building, so that the air currents tend to pass outward from the group of rooms containing plumbing fixtures, fresh air being admitted to other portions of the building. The facility with

which this can be accomplished, and also the proper grouping of fixtures and simplicity of the system of pipes will depend largely upon the architect.

The ornamentation of porcelain ware and of surrounding wood-work by raised or carved patterns is positively detrimental. A perfectly plain, smooth, impervious surface is more conducive to cleanliness.

Everything connected with house drainage and plumbing should be of the best material and most thorough workmanship. The best plumbing is not too good. By best plumbing is not meant the most showy, or necessarily the most expensive. Water closets and sinks are not the most appropriate places for gilt and tinsel. On the other hand, it is poor economy to risk health and life on cheap, bad work in the sanitary arrangements in our homes.

When the soil, ventilating and waste pipes are all in position, and before the fixtures are put in place, a test of the thoroughness of the work should be made. This can be done in a variety of ways. The following will be a very good test: Close up the main drain where the iron pipe terminates outside the house wall, also the exposed ends of all pipes where fixtures are to be connected, and the fresh air inlet, if there is any. The ends of lead pipes should be left somewhat longer than necessary, so that this can be conveniently done by flattening them, and closing with solder.

When all openings in the entire system of soil, waste and ventilating pipes are tightly closed below, fill the entire system with water from above nearly to the top, and mark the height at which the water stands. If no leakage is apparent and the water stands at the same level for some hours, the joints may be considered good. The entire work should be carefully inspected while under pressure, and joints re-calked where necessary.

It is not proper to connect waste pipes from refrigerators or safes, or overflow pipes from water tanks or cisterns directly with the sewers or waste pipes. The discharge from these can be often collected at a common receptacle, however, which is isolated from the sewers by special means.

CHAPTER XII.

COST AND ASSESSMENTS.

Comparative Cost of the Separate and Combined Systems.—No *general* comparison of the economy of the Separate and Combined Systems of sewerage can be made. It depends in all cases on the condition of each problem, and the relative economy in a particular case can be determined only by a competent engineer, after thoroughly considering the requirements to be met.

As indicated in a previous chapter, there can be no question as to which system will secure the most perfect and sanitary house drainage, whatever the conditions may be. In the Separate System proper we are seeking this with a single aim, and may adopt anything conducive to it and reject anything detrimental to it How far we may depart from this line from considerations of apparent economy is a serious question.

It must not be forgotten that we are establishing a complete system of subterranean communication between the dwellings of all classes of society, interposing but a small volume of water as a barrier to the circulation of air currents, and when street water is admitted we are introducing another element of danger.

In many of the smaller cities of the United States (and they are comparatively numerous, as shown in Table II) there can be no question as to the superior advantages of the Separate System in economy, efficiency, and adaptability to all the requirements to be met. In cities of this class it is folly to construct a Combined System ill-adapted to the work in hand. The question of relative cost, though favoring the Separate System, is, therefore, not a pertinent one.

A comparison as to cost can only be properly drawn in the case of cities where considerable areas are paved and the storm water from them cannot be carried to the nearest stream without accumulating in the gutters to a degree interfering with business or threatening damage to property.

The admission of storm water to small streams traversing a city is entirely proper and generally beneficial. Any filth brought from foul pavements is thoroughly removed by the after-flow of the rain which brings it, and also the filth accumulated in the bed of the streams during low stages of water, which is so potent a factor in pollution and the accumulation of which, despite the stringent ordinances in force in cities of this class against the pollution of streams, it seems well nigh impossible to prevent.

Even in the Combined System it is usual to provide overflows for the escape of a portion of the storm water into the natural drainage channels.

"No system of sewerage yet proposed in any city contemplates the removal of *excessive* storm water by means of sewers alone—such storms, for instance, as discharge for short intervals two or three inches of rain in an hour. These occur at long intervals and are of short duration and the damage is usually confined to limited areas, whilst the construction of sewers to meet the contingency would be attended with enormous expense over the whole city, both in construction and repair, and prove of doubtful efficiency when suddenly called upon, and extremely objectionable as conduits for the ordinary flow of sewage." —*Adams.*

In cities of this class, then, we may properly compare the cost of the Combined System uniting the house and manufacturing wastes with the storm water for removal in the same conduit on one hand, with the cost of the Separate System proper, supplemented by conduits for the separate removal of surface water, where such are necessary, discharging into the nearest water-course. Sewers for house drainage are required in every street or alley. Conduits for the removal of storm water from streets are required, with rare exceptions, only in alternate streets, extending from the natural drainage channels toward the summits.

It will thus be seen that even in very densely built portions of a city, if the sewage proper can be combined with the storm water without necessitating an extension of the large out-fall sewer, which otherwise would not be required, the sewers in alternate streets extending parallel with storm water conduits, and in every street intersecting them, may receive house drainage exclusively, to be finally discharged into the common out-fall.

In this case if the city be laid out in regular squares, the Separate System will reach three-fourths of the dwellings without requiring a double system in any street.

It often happens, however, that such a combination cannot be made without requiring the construction of a long line of out-fall sewer of large diameter, at a comparatively large cost, which, if the storm water was not combined with the sewage, might be of comparatively small size and cost.

In designing a system of sewerage, then, the vital question is not properly that of the comparative cost of the Separate and Combined Systems, but a question of the proper means to be adopted for doing the work required to be done.

Cost of the Separate System—The principal items in the cost of sewers are: the pipe, trenching, laying pipe and refilling the trench, man-holes, flush-tanks, lamp-holes and engineering and superintendence.

The pipe manufacturers issue price lists, and these with the discount (depending upon the season, amount required, etc.) can be obtained by applying to the agents or general offices.

The only very uncertain item in the list is the second—trenching, laying pipe and refilling. This will depend upon the nature of the soil in which the sewer is laid.

Quicksand is the most difficult material to manage. It will cost from two to five times as much to put in a sewer in quicksand as it will in ordinary earth.

Examples of Cost from Actual Work.—As a guide in estimating the cost of sewers of the Separate System a few instances of the cost of actual work are here given.

In Table XXI will be found a statement of bids received on sewer construction in Schenectady, N. Y.

The soil in which these sewers were proposed to be laid was, for the most part, favorable. It was necessary, however, to sheet pile the trenches nearly all the way. Very little hardpan was met in construction. About 1,500 feet of the Front Street main sewer was laid in quicksand, the water rising to an average depth in the trenches of about two and one-half feet. The cut under the New York Central Railroad, on Front Street, was peculiarly difficult, the depth of trench at this point being sixteen and one-half feet, the lower four feet of which was quicksand and water. More or less quicksand and water were encountered on all the streets leading from the lower levels of the town to the plateau on the east, and also in White, Romeyn, and Fonda Streets, South Avenue and Nott Terrace. On the eighteen-inch main in Fonda Street about two hundred feet of rock work was encountered, averaging about two and one-half feet deep. It was removed by the contractor at a cost of about ninety cents per cubic yard and no extra allowance was made therefor.

The conditions found in Schenectady do not seem to be widely at variance with those ordinarily met with.

The contract was awarded to the bidder whose name appears twelfth in the schedule of bids, at the prices therein stated.

Ninety-seven per cent. of the work was completed within six working months.

The following is a detailed estimate of the work as finally completed and represents the total cost of the work, exclusive of engineering, expenses of sewer commission, land damages, preparation of plans, records, etc.

Excavation	$10,823 43
Pipe and laying	12,229 37
Accessories	5,739 87
Total,	$28,792 67

A total cost, for construction proper, of $.55 per lineal foot.

The work afforded the contractor a reasonable profit, but it is doubtful if at present prices it could be duplicated. At the time bids were submitted common laborers could be hired at from one dollar to one dollar and twenty-five cents per day.

TABLE XXI.

BIDS ON SEWER CONSTRUCTION, SCHENECTADY, N. Y.

	Price per foot for excavation and back-filling under 6 feet.	Price per foot for excavation and back-filling over 6 feet and under 8 feet.	Price per foot for excavation and back-filling over 8 feet and under 10 feet.	Price per foot for excavation and back-filling over 10 feet and under 12 feet.	Price per foot for excavation and back-filling over 12 feet and under 14 feet.	Price per foot for excavation and back-filling over 14 feet and under 16 feet.	Price per lineal foot for furnishing and laying 8 inch pipe.	Price per lineal foot for furnishing and laying 10 inch pipe.	Price per lineal foot for furnishing and laying 12 inch pipe.	Price per lineal foot for furnishing and laying 18 inch pipe.	Price per man-hole, including materials and labor.	Price per flush-tank, including materials and labor.	Price per lamp-hole, including materials and labor.	Price per lineal foot for repaving.
Samuel Moak	$ .16½	$ .22	$ .90	$ .93	$ .40	$ .45	$ .25	$ .34	$ .41	$ .60	$ 48.00	$ 47.00	$ 5.50	$ .08
Hinds, Moffat & Co.	.24	.46	.70	.96	1.12	1.82	.23	.31	.38	.65	42.02	72.25	8.20	.05
J. A. Hallnan	.27	.35	.80	1.00	1.50	3.30	.22	.30	.38	.82	51.00	76.00	10.00	.04½
Doyle & Stanton	.37	.43	.54	.59	.72	.90	.18	.27	.35	52	38.00	40.00	2.25	.12
Robert Bryce	.27	.29	.34	.39	.55	.95	.23½	.31½	.38	.66	54 75	85.50	8.79	.05
Spaulding & Lenane	.42	.47	.62	.90	1.05	1.20	.18	.27	.33	.57	45.00	55.00	5.50	.12
B. J. Coyle	.37	.45	.50	.56	.62	.70	.33⅓	.50	.60	1.00	30.00	45.00	10.00	.07
S. E. Babcock	.28	.33	.48	.60	.70	1.00	.25	.33	.38	.75	40.00	50.00	1.75	.07
Sloan & McIlvain	.34	.41	.52	.63	.74	.87	.27	.34	.39	.59	25.00	50 00	8.00	.05
Sherman & McDonald	.25	.36	.53	.95	1.50	2.00	.24	.31	.36	.58	45.00	65.00	7.50	.20
W. E. Dean	.20	.40	.60	1.10	1.25	1.50	.23	.33	.47	.60	36.00	50.00	4.00	.10
B. VanVranken	.13	.20	.30	.35	.40	.50	.19	.26	.32	.55	30.00	35 00	6.00	.03½
J. McEncroe	.22	.28	.75	.85	.95	1.10	.17	.23	.27	.49	34.00	40 00	7.75	.08
S. V. Trull	.13	.16	.18	.20	.30	.38	.18	.30	.39	.50	40.00	30.00	1.50	.01
M. Nolan	.11	.26¼	.42½	.55	.82¼	.98	.16¾	.24½	.30	.58¼	37.27	44 00	5.00	.05½

Prices of material were also depressed. The entire cost of the system, including man-holes, flush-tanks and all accessories, all expenses of engineering, and preparation of plans and records, expenses of sewer committee, and all costs, of whatever nature, chargeable to the sewers was $.72 per lineal foot.

A tax of $2.50 per capita on the population accommodated by these sewers, or a tax of one-half of one per cent. on the assessed valuation of the city would have paid their cost.

In Table XXII will be found a statement of bids received for the construction of a system of sewers in West Troy, N. Y. The contract was awarded to the bidder whose name appears first in the Table.

The general statistics of the sewers are as follows:

Total length of sewers (18 8-10 miles)	96,319 feet
Total cost (exclusive of general expenses)	$95,241.78
Total cost per foot " " "	99 cents
Deepest trench (rock)	16 feet
Number of flush-tanks	116
Largest size of pipe	18 inches
Smallest size of pipe (with few exceptions)	8 "
Number of canal crossings	7
Number of outlets	7
Longest continuous line of sewer	About 9,000 feet
Number of flushing inlets from canal	6
Datum level	Low water in the Hudson River
Length of drain tile	48,926 feet

TABLE XXII.

BIDS FOR CONSTRUCTION OF THE WEST TROY SEWERS.

	PRICE PER LINEAL FOOT.																			
	Excavating and Back-Filling under 6 feet.	Excavating and Back-Filling 6 to 8 feet.	Excavating and Back-Filling 8 to 10 feet.	Excavating and Back-Filling 10 to 12 feet.	Excavating and Back-Filling 12 to 14 feet.	Excavating and Back-Filling 14 to 16 feet.	6-Inch Pipe laid.	8-Inch Pipe laid.	10-Inch Pipe laid.	12-Inch Pipe laid.	15-Inch Pipe laid.	18-Inch Pipe laid.	3-Inch Tile Drain laid.	Repaving.	Price per Lineal Ft. for Ft. in depth for rock.	Iron Pipe per Ton laid.	Man-Hole.	Lamp-Hole.	Flush-Tank.
	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$
Emmet Flagler........	14	18	22	25	40	55	18	23	33	40	52	76	05	05	14	42 00	38 00	7 50	40 00
Andrews & VanVranken	20	22	40	60	1 00	1 50	18	21	30	36	48	65	20	15	15	45 00	30 00	5 00	28 00
John McEncroe	21	21½	30	40	50	56	18	20½	35	43	58	75	15	20	20	50 00	40 00	7 50	40 00
W. Stanton...........	30	37	38	46	63	78	18	21	30	36	45	85	05	12	18	43 29½	35 00	11 54	50 00
Mahone & McKenna...	20	26	37	58	80	96	16	21	32	29	50	73	07	04	24	45 00	40 00	7 50	40 00
Broderick & Jackson...	15	20	30	45	65	85	18	23½	34	42	55	75½	10	08	30	50 00	42 00	7 00	42 00
Cummings & Upper....	15	20	55	1 05	2 30	3 75	16	20	30	36	47	70	03	10	30	39 00	29 00	5 75	30 00
M. J. Haney	15	18	50	1 05	2 30	3 75	16	20	30	36	47	70	03	10	28½	39 00	30 00	5 50	30 00
John Cox & Co........	75	95	1 05	1 10	1 15	1 20	90	95	1 05	1 15	1 25	155	50	10	35	50 00	60 00	50 00	100 00

The system is almost entirely the Separate System. The only exception being a small territory tributary to the Sixth street main from which surface water is admitted. As will be seen by the accompanying map, the village has a river front on the Hudson of about two miles. This affords an opportunity of employing several outlets, and makes it possible to carry the sewage to its outfall in the river by short, direct lines, except in special cases. By dividing the whole territory into several distinct systems, each with a separate outlet, large mains were avoided and the cost of construction materially reduced.

The village extends back from the river about half a mile, and as the general direction of the main was towards the river, no very long lines were necessary. The surface of the ground falls towards the river with sufficient slope for sewer grades, so that flat grades were rarely necessary. The Erie canal runs through the village from north to south, nearly parallel to the river, and about 800 feet from it.

The surface of the water in the canal is on the average about level with the natural surface of the ground near the canal; in places rising above, and in places falling below it.

Besides the main line of the canal there are two branch canals, leading to the river, and two large basins. The canal, branches and basins, greatly complicated the work of designing the sewers, and increased the cost of construction.

The material to be excavated from the trenches consisted of gravel, sometimes containing large boulders, clay, and rock, varying in quality from soft shale, which yielded readily to the pick, to hard argillaceous rock, seamed with quartz.

The canal banks intercepted the natural flow of the ground water towards the river and materially increased the trouble from this source. Since the water in the canal was about level with the natural surface of the ground near the canal, it is readily seen that the ground in the vicinity of the canal would be water-soaked, and that wet cellars and difficult trenching might be expected. In several places in the village the rock came to the surface in ridges, leaving pockets of considerable extent

without drainage. In these places wet cellars were common. So little attention had been given to drainage that in some places stagnant pools of considerable extent remained all summer.

The following is a statement in detail of the cost of the system:—

Earth Excavation	$16,008.23
Rock Excavation	26,891.79
Sewer pipe laid in the trench	25,716.74
Drain tile laid in the trench	2,446.34
Manholes	4,617.00
Flush-Tanks and connections and Flushing Inlets	11,699.60
Lamp-Holes	795.00
Iron pipe—laid	4,209.26
Outlets and miscellaneous	4,513.04
Expenses of Sewer Commission, engineering, land damages, superintendence	16,902.42
	$113,799.42

Cost per foot of the entire system.......$1.18

The aggregate capacity of all the sub-systems enumerated is 3,940,000 gallons of sewage proper per day. Equal to 75 gallons per diem per capita for a population of 52,530, and at the same time a capacity to discharge about 2,000,000 gallons of subsoil water per day. The total volume on this assumption will in no case fill the sewer more than 71-100 of its diameter at the time of average maximum daily discharge.

The following is a schedule of bids received for constructing a system of sewers in Dayton, Ohio.

TABLE XXIII.

BIDS FOR CONSTRUCTION OF SEWERS IN DAYTON, OHIO.

Opened October 13, 1890.

BIDDERS.	PRICE PER LINEAL FOOT.																									PRICES EACH.					
	PIPE LAID.							DRAIN TILE LAID.				BRICK SEWER.				EXCAVATION.								Repaving.	Man-Hole.	Lamp-Holes.	Flush-Tanks.	Iron Pipe, Price in Tons.	Embankment Cubic Yards.	Clay Puddle, Cubic Yards.
	18 in	15 in	12 in	10 in	8 in	6 in	5 in	6 in	5 in	4 in	3 in	42 in	40 in	36 in	30 in	-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20							
Frank Whitley.	1.60	1.25	1.10	1.00	.65	.55	.55	.04	.03	.02	.02	3.90	3.90	3.80	4.00	.10	.06	.06	.06	.20	.20	.20	.20	.25	20.00	3.00	25.00	60.00	.60	1.50
D. F. Minehan.	.77	.52	.36	.30	.23	.13	.11	.08	.07	.06	.06	4.00	4.00	4.00	3.50	.23	.37	.39	.60	.90	.95	1.08	1.30	.45	34.00	5.00	21.00	55.00	.40	1.25
John Munger..	.60	.50	.33	.26	.21	.14	.12	.05	.04	.03	.023	2.39	2.34	2.05	1.70	.20	.35	.40	.60	1.10	1.20	2.00	2.50	.12	25.00	3.00	25.00	38.25	.30	2.00
Robert J. Paul.	.67	.53	.43	.37	.24	.17	.14	.12	.095	.09	.09	2.90	2.90	2.55	2.20	.24	.40	.44	.59	.85	1.00	1.24	2.25	.70	34.00	9.00	85.00	57.00	.67	1.40
Bruno Ritty....	.76	.52	.40	.33	.23	.18	.16	.14	.12	.10	.08	2.78	2.41	2.25	2.05	.16	.20	.26	.37	.45	.63	.96	1.04	.15	25.10	9.35	23.00	50.00	.20	.50

This system is still in process of construction. So far as the work is complete the cost of construction proper, not including the expenses of the commission for land damages, engineering and other general expenses of a like character is as follows:

Brick sewer,	42 inches in diameter,	1304 feet
	40 " " "	30 "
	36 " " "	3380 "
	30 " " "	1809 "
Pipe sewer,	18 " " "	900 "
	12 " " "	624 "
	10 " " "	7853 "
	8 " " "	30478 "
Man-Holes		135
Flush-Tanks		45
Lamp-Holes		166
42 inch iron outlet		100 feet.

Cost of construction to date $57,040 88

Cost per foot including man-holes, flush-tanks, etc., $1 25

The work has been peculiarly difficult for the reason that nearly all of the brick sewer has been laid in ground below the level of the river at times and it has been necessary to keep a steam pump in operation continuously day and night, and in some instances two of them. The remaining portion of the work is much less difficult and the sewers of smaller diameter, being mainly laterals, so that the cost per foot of the entire system will be considerably reduced.

A pumping station has been constructed capable of handling 20,000,000 gallons of sewage per day at a cost of $6,562.26 for the building and $5,810.00 for the machinery. This will add about $.19 per lineal foot to the cost of that portion of the system which it is proposed to construct at present. The pumping station will ultimately serve a much wider territory however.

The following Table gives in a condensed form valuable information as to the cost, etc., of thirty-five sewerage systems. It was compiled from information gathered by the Public Improvement Commission of Troy, N. Y., and appears in a more extended form in the *Engineering Record* for October, 1891:

TABLE

DATA OF COST AND CONSTRUCTION

City.	System.	Per Cent. Min. Grade Pipe Sewers.	Sewage per Cap. Daily Gallons.	Cost of Cleaning.
Akron, O.	Combined	0.6 rarely.	100	$300 annually
Alleghany, Pa.	"	0.25 to 0.6		Nothing
Altoona, Pa.	"	1	70	
Augusta	"	0.25		
Bloomington	"	0.2		Nothing
Boston	"	1	90	
Buffalo	"	0.15	60	
Burlington, Vt.	"	0.25		
Cambridge	"	0.16		
Camden, N. J.	"	0.5	90	$60 per mile.
Chicago	"	0.2		$110 per mile
Cincinnati	Combined & separate	25 (?)	60	
Cohoes	Combined	0.5	40	Nothing
Council Bluffs	"	0.1		$200 per mile
Detroit	"	0.5		$13.56 "
Dubuque	Separate	8", 0.35; 24", 0.07	50	Nothing
East Saginaw	Combined	0.24	20	$10 per mile.
Elmira	"	1		
Erie	"	0.33		
Grand Rapids	"	25 (?)		
Kansas City	"			
Kingston	Separate	0.15	5	
Lancaster	Combined			Nothing
Lawrence	"	0.4		
Lincoln	Separate	0.1		
Little Rock	"	0.17		$155 per mile
Milwaukee	Combined	0.22	150	
Newark	"	0.42		
New Haven	"	0.25		$19.98 pr mile
Omaha	Combined & separate	0.5	80	Nothing
Philadelphia	" "		50	
Portland, Me.	Combined	0.25	75	$37.98 pr mile
Providence	"	0.2		$64.50 "
Rochester	"	0.25		$1,000 ann'lly
Syracuse	"	0.25		Nothing

XXIV.

OF THIRTY-FIVE SEWERAGE SYSTEMS.

Cost of Pipe Sewers.						Cost of Brick Sewers.				Average Depth of Sewers, feet.
8″	10″	12″	15″	18″	24″	30″	36″	48″	60″	
$0 30	......	$0 30	$1 50	.....	$2 50	$2 50	$2 50	$9 00	$9, 00	9
......	......	......	1 50	$1 75	2 25	4 00	4 50	5 50	7 00	11 to 12
......	......	......	......	......	......	3 00	3 20	6 70	......	10 to 12
0 25	0 35	0 38	0 65	0 70	......	1 13	1 82	2 85	4 09	5 to 10
......	......	0 60	0 70	1 00	......	......	2 00	......	4 00	10
1 50	1 50	1 50	1 75	2 00	3 00	3 50	3 75	5 00	8 00	10
......	1 00	1 00	1 20	1 50	2 00	2 00	3 25	4 50	5 50	9 to 20
1 00	1 14	1 25	1 50	2 15	.. ...	3 70	3 67	4 00	.....	10
0 82	0 95	1 14	1 50	1 75	2 00	2 12	.....	.....	......	9
......	......	0 90	1 10	......	......	1 30	1 50	3 00	6 00	8
......	......	0 95	1 07	1 40	1 70	2 22	3 25	4 14	......	....
1 50	1 75	2 00	2 25	2 50	3 00	4 00	5 00	7 50	9 00	13
......	0 75	0 80	0 90	1 25	2 10	.....	......	......	6 00	9
0 40	0 46	0 54	0 64	0 82	1 67	1 82	2 60	......	5 20	6 to 8
......	......	......	......	......	.....	1 20	......	......	4 50	4.5
0 65	0 70	0 80	1 00	1 30	1 60	2 65	.....	......	......	10
......	......	0 65	0 70	0 80	.....	......	... .	4 50	6 00	10 to 18
.....	......	1 10	......	......	2 25	......	3 00	4 00	......	10 to 12
......	.....	1 40	1 85	3 05	3 70	4 20	....	......	......	10
9 in.	0 90	1 25	.....	......	......	......	......	......	......	8
......	......	0 85	1 00	1 40	......	2 45	3 50	3 90	4 60	12
0 77	......	......	0 88	......	1 37	......	......	......	......	9
......	......	......	......	......	......	1 00	1 25	1 50	2 00	7
......	1 15	1 30	1 70	2 10	2 25	4 40	4 90	6 25	10 00	7½ to 8
0 40	0 45	0 60	0 75	1 00	1 55	......	4 50	5 60	6 50	8 to 12
......	......	......	......	......	2 50	......	......	..... .	....	10
......	......	1 25	1 35	1 65	......	3 10	3 65	4 75	7 00	10½ to 13½
0 55	0 80	0 88	1 12	1 36	1 55	3 20	3 46	5 63	6 55	10
......	......	1 29	1 68	2 05	3 21	4 28	5 83	7 50	16 47	10 to 12
0 70	0 80	0 90	1 10	1 40	2 75	3 80	3 90	4 00	9 80	12½
2 00	t	o	2 25	2 25	2 25	2 25	2 25	......	5 00	10 to 15
0 64	1.036	1.361	2 39	1.865	2 54	3 03	3 97	7 76	8 36	7½ to 9
......	......	1 48	1 82	2 00	3 70	4 33	5 05	6 41	7 80	11
......	.....	1 00	1 25	1 50	2 50	......	5 00	.....	......	7 to 10
0 40	0 50	0 70	1 00	1 25	1 60	2 50	3 25	4 00	7 60	10

The Table also gives valuable information as to the practice, with reference to grades, cost of cleaning and depth of sewers in the cities mentioned.

Examples of Cost Computed from Time Book.—Tables XXV, XXVI, XXVII and XXVIII were compiled by Mr. W. E. Ely. They were computed from notes taken in actual work, and represent actual cost to the contractor. An allowance of fifteen to twenty-five per cent. above these prices would be proper in making preliminary estimates of cost. The soil was loam, sand, and gravel, and the roadway compacted gravel. The trenches were sheet piled the entire length.

TABLE XXV.

ACTUAL COST OF LABOR AND MATERIAL.

Size of Pipe.	Depth of Cut.	Cost of Pipe per foot.	Cost of Trenching and Back-filling per foot.	Cement.	Gaskets.	Laying Pipe.	Superintendence.	TOTAL.
		Cts.	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*
10 inch.	....	19	......	1.14	.60	4	......	......
12 "	....	29	......	1.55	.87	5	......	......
10 "	Under 6½ ft.	19	29.92	1.14	.60	4	9.0	63
10 "	6½ to 9 ft.	19	36.82	1.14	.60	4	11.0	72
10 "	9 to 12 ft.	19	*57.68	1.14	.60	4	15.5	87
10 "	12 to 15 ft.	19	46.70	1.14	.60	4	12.6	84

*Considerable water was encountered at this depth, which accounts for the increased cost of excavation.

Laborers' wages, $1.50 per day; superintendence, $10.00 per day. About one-sixth of the trenching was in water whose average static level was two feet above the grade line. The soil was

of average compactness. The trenches were sheet piled nearly the entire length.

TABLE XXVI.

ACTUAL COST OF LABOR AND MATERIAL.

Size of Pipe.	Depth of Cut.	Cost of Pipe per foot.	Cost of Trenching and Back-filling per foot.	Cement.	Gaskets.	Laying Pipe.	Superintendence.	TOTAL.
		Cts	Cts.	Cts.	Cts.	Cts.	Cts.	Cts.
6 inch.	Under 6½ ft.	9	15	.54	.47	3	1.5	29
6 "	6½ to 9 ft.	9	21	.54	.47	3	4.0	38
6 "	9 to 12 ft.	9	28	.54	.47	3	7.0	48
6 "	12 to 15 ft.	9	*76	.54	.47	3	18.0	107
6 "	15 to 18 ft.	9	60	.54	.47	3	30.0	103
8 "	....	12	.....	.77	.58	3	......	.....
10 "	....	19	......	.84	.60	4	......	......
12 "	....	24	......	1.55	.87	5	......	......

*Considerable water was encountered at this depth, which accounts for the increased cost of excavation.

Laborers' wages, $1.50 per day; superintendence, $10.00 per day. Nearly all trenching was dry. The soil was rather favorable than otherwise, but required sheet piling.

TABLE XXVII.

ACTUAL COST OF LABOR AND MATERIAL.

Size of Pipe.	Depth of Cut.	Cost of Pipe per foot.	Cost of Trenching and Back-filling per foot.	Cement.	Gaskets.	Laying Pipe.	Superintendence.	TOTAL.
		Cts.	Cts.	Cts.	Cts.	Cts.	Cts.	Cts.
8 inch.	Under 6½ ft.	12	35	1.1	.58	3	9.83	61
8 "	6½ to 9 ft.	12	32	1.1	.58	3	8.00	56

Laborers' wages, $1.50 per day; superintendence, $10.00 per day. Water was found about one-fourth of the distance, but did not seriously retard the work. The soil was of average compactness.

TABLE XXVIII.

ACTUAL COST OF LABOR AND MATERIAL.

Size of Pipe.	Depth of Cut.	Cost of Pipe per foot.	Cost of Trenching and Back-filling per foot.	Cement.	Gaskets.	Laying Pipe.	Superintendence.	TOTAL.
		Cts.	Cts.	Cts.	Cts.	Cts.	Cts.	Cts.
12 inch.	Under 6½ ft.	26.25	18.0	3.45	1.16	4.40	11.8	65
12 "	6½ to 9 ft.	26.25	27.5	3.45	1.16	4.40	16.5	79
12 "	9 to 12 ft.	26.25	46.5	3.45	1.16	4.40	16.5	98
12 "	Over 12 ft.	26.25	76.5	3.45	1.16	4.40	29.5	141

Laborers' wages, $1.50 per day; superintendence, $10.00 per day. Much of the work was in wet trenches, requiring about

one man in every ten at the pump. In some of the deep trenching the static level of the water was five feet above the grade line. The soil was tolerably compact, except where water was found, where there was quicksand.

Table XXIX, taken from the Report of the Bureau of Sewers of Chicago, 1891, shows the cost of the sewers built in the City of Chicago in 1890. These sewers are on the combined plan.

TABLE XXIX.

NEW SEWERS AND CATCH BASINS BUILT IN CHICAGO DURING THE YEAR 1890 AND COST OF SAME.

Length.	Size.	Average Cut.	Average Cost per Foot.	Amount.
11,525	9 inch.	10.3	$0 98	$11,294 50
119,689	12 "	7.7	1 06	126,870 34
114,503	15 "	8.1	2 20	137,403 60
14,016	18 "	9.1	1 47	20,603 52
4,400	20 "	10.8	1 91	8,404 00
57,447	2 foot.	9.2	2 22	127,532 34
17,298	2½ "	10.9	2 65	45,839 70
7,762	3 "	8.4	3 50	27,167 00
5,942	3½ "	12.3	3 86	22,936 12
2,705	4 "	6.5	4 37	11,820 85
6,932	4½ "	10.4	5 00	34,660 00
10,767	5 "	9.5	4 41+	58,277 47
2,623	5½ "	14.5	6 44	16,892 12
610	6 "	10.0	5 71	3,483 10
1,650	7 "	12.5	9 95	16,417 50
1,334	7½ "	10.0	9 35	12,472 90
379,203	....	....	....	$682,075 06

Cost of 2,986 catch-basins built............	$119,440 00	
Cost of 6,709 cubic yards of rock excavated..	23,483 00	
		$142,923 00
Total for sewers and catch-basins....................		$824,998 06

The cost of the entire Combined Sewerage system of the City of Chicago, up to and including 1890, is shown by the same report to be about $2.65 per foot. The system consists of about 784.737 miles, of which 360.694 miles are constructed of brick and 424.043 miles of vitrified clay pipe.

From the last annual report of the city engineer of Providence, R. I., it appears that the average contract cost of labor per foot on the different sizes of sewers built in Providence during the last three years has been as follows:

8 inch pipe in basin connections................	$0 63
12 " " sewer..............................	1 20
15 " " "	1 34
16 " single coarse brick sewer	1 70
18 " " " " "	2 05
20 " " " " "	2 03
22 " " " " "	1 50
24 " " " " "	2 55
48 " double " " "	3 25
20x30 inch single coarse brick sewer	2 15
22x33 " " " " "	2 60
24x36 " " " " "	2 30
26x39 " double " " "	2 60
28x42 " " " " "	3 00
36x54 " " " " "	2 65
38x57 " " " " "	3 67
40x60 " " " " "	5 47
Rock excavation per cubic yard................	4 00

The average cut for 12 and 15 inch pipe sewers was about 12 feet, for brick sewers 13 and 15 feet, with the exception of the

40 x 60 inch sewers, when the average cut was about 24 feet. The excavation was mostly in sand and gravel.

Maintenance of Sewerage.—The cost of cleaning and repairing sewers, the cost per mile, and number of miles; also the number of catch basins and man-hole chambers distributed in the three divisions of the City of Chicago, according to the report of 1890, is as follows:

Divisions.	Miles of Sewers.	Number of Catch-Basins.	Number of Man-Hole Chambers.
West	319.074	10,968	11,337
South	312.246	10,041	12,258
North	153.417	5,480	6,395
Totals	784.737	26,489	29,990

The cost of repairing sewers during the year was $14,648.97, being an average of $18.67 per mile.

The cost of cleaning was $107,873.34, making the average cost $137.46 per mile.

The total cost of both repairs and cleaning was $122,522.31, an average cost of $156.13 per mile.

Accounts, as found in the reports of Sewer Departments, are rarely classified so that the cost for maintenance and repairs of the Separate System can be isolated. The cost of maintenance is very slight, however, being confined almost entirely to the cost of an inspector who has the care of the system and inspects it at frequent intervals.

According to the report of the Sewer Commissioners of Brockville, Ont., the yearly cost of a system of about nine miles, costing about $100,000.00 is $400.00, $200.00 of which is for repairs.

The cost of maintenance of forty-two miles of sewers on the Separate System, in Memphis, in 1889, is given as follows in the Engineer's Report.

MAINTENANCE.

Repairing flush-tanks....................	$ 1,648	55	120
Repairing man-holes	43	02	3
135 obstructions removed..................	718	01½	50
Repairing streets.........................	361	11	
Repairing damages.........................	30	10	
Repairing sewers..........................	127	81	10
Cleaning sewers, main.....................	89	46	
Cleaning sewers, laterals.................	93	20	19
Tools, etc................................	304	48	25
Office expenses	88	55	10
Superintendent	1,200	00	
Miscellaneous.............................	185	93	329
	$4,890	22½	

Some of the items, particularly $1,648 for repairing flush-tanks, seem to be large for an average year.

Sewer Assessments.—The following are some of the many plans adopted for assessing the cost of sewers:

1. By a general sewer tax, paying for the sewers as fast as they are built.

2. By issuing bonds and providing for their gradual payment by a general tax.

3. By assessing the property benefited.

4. By paying for the sewers by a general tax, and charging for permits to connect private sewers.

5. By assessing the property adjoining the sewers in proportion to the frontage of each lot.

6. By assessing the adjoining propery in proportion to the area of each lot.

7. By assessing the adjoining property in proportion to the value of each lot.

8. By assessing a certain part of the cost on the adjoining property in proportion to the frontage (or area, or value) and raising the remainder by a general tax.

9. By assessing a certain uniform amount per foot front on adjoining property and paying the remainder by a general tax.

The method of assessing the cost of a sewer upon "the property benefited" gives rise to perplexing questions. The judgment of different individuals will differ widely as to the limits of the districts benefited, the proportion of benefit derived by each lot owner and the relative value of the lots.

In assessing the cost of sewers in any section on the abutting property a difficulty arises from the fact that some parts of any system will be much more expensive than others, and the extra cost will not be justly chargeable to the adjoining property.

In designing any system of sewers, the sewage of a whole town, and the convenience of all the citizens, will require the construction of mains costing from two to four times as much as the laterals, and the conformation of the ground may necessitate much deeper cuts in some localities than in others. To compel the owners of the lots adjoining the mains and deep cuts to pay all the cost of them, when the extra cost is incurred to benefit distant territory, is a manifest injustice. The burden of the expense may be more nearly equalized, either by paying for the whole system by a general tax or by assessing upon the lots a uniform amount per foot front (or in proportion to area, etc.), and paying for the remainder by a general tax.

To charge for connecting private sewers with the public sewers, more than a nominal fee to pay for inspection, is not advisable. The policy should be to encourage the citizens to use the sewers and abandon the objectionable methods for the disposal of sewage which are employed where sewers are not used.

The most advisable method of sewer assessment to adopt in any place will depend upon the conditions. Among the most important considerations are the following: Whether the whole system of sewers is to be built at once or by piecemeal, whether there is to be one outlet or several—that is, whether there are distinct sewer districts, the cost of the sewers and the financial ability of the citizens.

It is evidently impossible by any of the above methods to distribute the cost of sewers with absolute justice. The method of general taxation discriminates against outlying property adjoining which no sewers are built. It is applicable to districts the whole of which are tributary to one system where the system is all constructed at once so that all property is benefited.

The method of assessing in proportion to frontage discriminates against shallow lots and vacant property. The method of assessing according to area discriminates against deep lots and vacant areas.

The method of assessing according to valuation, especially where the tax is all spread in one payment, discriminates against improved property as against vacant property which may possibly be improved the following year.

According to information gathered by Cambridge, Mass., it appears that out of 66 cities 13 paid the cost of sewers by a general tax and 53 assessed benefits.

Of the 53 assessing benefits, 14 assessed the whole cost, 15 assessed three-fourths of the cost, 10 assessed three-fourths of the cost according to foot frontage, 12 assessed one-half to three-fourths the cost and 2 assessed less than one-half the cost.

The prevailing rule among those who clearly state their practice is to divide the cost according to frontage.

The City of Providence has given considerable attention to this question and assesses according to frontage for a certain depth from the street, and for a certain depth farther assesses according to area.

This combination of the methods of area and frontage tends to correct and equalize the discriminations of either method used singly.

Whatever method of assessing benefits be adopted there will be a proportion of property owners that will be distressed if the whole of their assessments be levied for collection in one payment as is almost universally the custom in the United States.

In many cases it means to the owners of such property practically a forced sale of the property. This seems to be a proper field for the application of the principles of the Building and Loan Association, or in other words a massing of capital and an association of interests for the purpose of distributing costs over a series of years and obtaining money in comparatively large amounts at correspondingly low rates. The application of this method to special assessments, whichever of the above mentioned methods of determining the proportion to be assessed be adopted, is not at all intricate as will be shown later. The municipality is not less interested in so distributing the cost than is the individual. Statistics show that a very small proportion of cities "pay as they go." Almost without exception they borrow in large amounts on long time and usually at low rates. This is unavoidable in a wise policy of public improvements and sound finance. Otherwise public works would necessarily be constructed piecemeal at a greatly increased cost, and a great loss of efficiency, or on the other hand, if the proper amount of capital were massed at one time for the economical and efficient construction of a system of sewers, water works or other public works of corresponding magnitude the variations in the percentage of taxes levied from year to year would be appalling and undoubtedly there would be an exodus of the population.

Let us assume, for the purpose of illustrating, that it is proposed to construct a system of sewers for a certain district, which is entire within itself (whether converging to a single outlet or not does not matter so long as a like proportion of the cost may properly be distributed equally over the territory in question). Let us assume also that the cost of the system complete, including general and extraordinary expenses is $1.00 per lineal foot and that private property is deemed to be benefited to the extent of $.40 per lineal foot on the frontage plan on each side of the street and that the balance of the cost, which will be somewhat in excess of $.20 per lineal foot, by reason of street intersections and the rebates which it will be necessary to allow in order to equalize the assessments on corner lots and triangular pieces, be

borne by the city. We will assume also that this amount borne by the municipality is equal to one-third of the total cost for the purpose of simplifying the problem, and that it is desired to distribute the cost of the sewers over the term of 10 years, principal and interest to be met by 10 equal, annual payments.

In the case of a property owner having an ordinary lot of 50 feet frontage the total assessment will be $20.00. In Table XXX will be found the amount of equal annual payments, of principal and interest combined, necessary to cancel a loan of $100.00 at various rates, and maturing in any number of years, from one to fifty.

TABLE XXX.

INSTALLMENT TABLE.

Showing the amount of equal annual payments (of principal and interest combined) necessary to cancel a loan of $100. at 3, 3½, 4, 4½, 5, 6 and 7 per cent., payable annually and maturing in any number of years from 1 to 50.

NUMBER YEARS IN WHICH LOAN EXPIRES.	PER CENT. PER ANNUM.						
	.03	.03½	.04	.04½	.05	.06	.07
1	103.000	103.500	104.000	104.500	105.000	106.000	107.000
2	52.261	52.657	53.020	53.413	53.780	54.544	55.309
3	35.362	35.699	36.026	36.370	36.726	37.411	38.105
4	26.903	27.229	27.550	27.877	28.202	28.857	29.523
5	21.832	22.147	22.464	22.778	23.096	23.741	24.389
6	18.460	18.771	19.077	19.386	19.702	20.337	20.980
7	16.049	16.353	16 662	16.969	17.282	17.914	18.555
8	14.244	14.548	14.852	15.161	15.472	16.103	16.747
9	12.843	13.145	13.450	13.757	14.069	14.702	15.348
10	11.723	12.024	12.330	12.637	12.950	13.586	14.238
11	10.808	11.109	11.416	11.725	12.039	12.679	13.336
12	10.046	10.348	10.656	10.966	11.283	11.928	12.590
13	9.403	9.707	10.014	10.328	10.646	11.296	11.965
14	8.853	9.157	9.467	9.782	10.103	10.759	11.434
15	8.377	8.683	8.994	9.311	9.634	10.296	10.979
16	7.961	8.268	8.582	8.902	9.227	9.895	10.586
17	7.596	7.904	8.220	8.542	8.870	9.544	10.242
18	7.271	7.580	7.899	8.224	8.555	9.236	9.941
19	6.981	7.294	7.614	7.941	8.275	8.962	9.675
20	6.722	7.036	7.358	7.688	8.024	8.718	9.439
21	6.487	6.804	7.128	7.460	7.800	8 500	9.229
22	6.275	6.593	6.920	7.255	7.597	8.305	9.041
23	6.081	6.402	6.731	7.068	7.414	8.128	8.871
24	5.905	6.227	6.559	6.899	7.247	7.968	8.719
25	5.743	6.068	6.401	6.744	7.095	7.823	8.581
26	5.594	5.921	6.257	6.602	6.956	7.690	8.456
27	5.456	5.785	6.124	6.472	6.829	7.570	8.343
28	5.329	5.660	6.001	6.352	6.712	7.459	8.239
29	5.212.	5.545	5.888	6.241	6.605	7.358	8.145
30	5.102	5.437	5.783	6.139	6.505	7.265	8.059

(Table concluded on next Page.)

TABLE XXX CONTINUED.

NUMBER YEARS IN WHICH LOAN EXPIRES.	PER CENT. PER ANNUM.						
	.03	.03½	.04	.04½	.05	.06	.07
31	5.000	5.337	5.686	6.044	6.413	7.179	7.980
32	4.905	5.244	5.595	5.956	6.328	7.100	7.907
33	4.816	5.157	5.510	5.875	6.249	7.027	7.841
34	4.732	5.076	5.432	5.798	6.176	6.960	7.780
35	4.654	5.000	5.358	5.727	6.107	6.897	7.723
36	4.580	4.928	5.289	5.661	6.043	6.839	7.672
37	4.511	4.861	5.224	5.598	5.984	6.786	7.624
38	4.446	4.798	5.163	5.540	5.928	6.736	7.579
39	4.384	4.739	5.106	5.486	5.876	6.689	7.539
40	4.326	4.683	5.052	5.434	5.828	6.646	7.501
41	4.271	4.630	5.002	5.386	5.782	6.606	7.466
42	4.219	4.580	4.954	5.341	5.739	6.568	7.434
43	4.170	4.533	4.909	5.298	5.699	6.533	7.404
44	4.123	4.488	4.866	5.258	5.662	6.501	7.376
45	4.078	4.445	4.826	5.220	5.626	6.470	7.350
46	4.037	4.405	4.788	5.184	5.593	6.442	7.326
47	3.996	4.367	4.752	5.151	5.561	6.415	7.304
48	3.958	4.331	4.718	5.119	5.532	6.390	7.283
49	3.921	4.296	4.686	5.089	5.504	6.366	7.264
50	3.887	4.263	4.655	5.060	5.478	6.344	7.246

Assume that the municipality can obtain money at four per cent. for the time stated. From the table we ascertain that a loan of $20.00, maturing in ten years at 4 per cent. will be canceled by 10 equal annual payments of $2.46 each.

If it be assumed that the cost of the entire improvement be $150,000.00 and the aggregate amount assessed against the property by special assessment by any of the methods described be $100,000.00 and the amount borne by the municipality at large be $50,000.00 as previously stated, we find from the table that the amount to be borne by the city at large will be paid by 10 equal annual payments of $6,165.00, which is the amount to be levied by general tax each year, and the aggregate of the special assessments against the property frontage will be $12,330 each year.

A separate account should of course be kept of the fund and all that remains to be done is to add the several amounts charged against each property (corresponding to the $2.46 in the case cited) to the yearly assessment of the property and to add the municipality's proportion, (corresponding to $6,165.00 in the case cited) to the amount to be levied in the general tax roll each year for ten years, until the account is closed. The clerical work in this method is not more than when others are used.

In some cases loans can be secured at a lower rate on bonds maturing after a stated number of years and bearing annual interest. Where it is desirable to secure funds in this manner the method above outlined can be used to provide a sinking fund for the payment of these bonds at maturity. It is by this method that the State of Michigan has been paying its war bonds.

CHAPTER XIII.

COMBINED SEWERS.

Under some circumstances it may be necessary to construct combined sewers. When this is the case the size of the sewers is determined by the amount of storm water to be provided for. The volume of sewage proper is so small in comparison with the volume of the storm water during the continuance of a storm that the sewage need not be taken into consideration.

In determining the size of "Combined Sewers" the following points must be taken into consideration:

1. The area from which the storm water is to be gathered.
2. The rate of rain-fall.
3. The relative proportion of the roofed and paved area to the whole area to be drained.
4. The nature of the soil in the unpaved part of the area.
5. The amount of ground water.
6. The natural grade of the surface.
7. The available grade for the sewer.

The rate of rainfall has been quite generally determined in those sections which have been long enough settled to feel the necessity for sewers.

It is evident that the larger the proportion of the roof and paved area the larger will be the percentage of the rainfall to be provided for by the sewers. The permeability of the soil in the unpaved areas will also materially effect the proportion of rainfall which reaches the sewers.

The grade of the surface will determine the rapidity with which the storm water will flow to the sewer, and the grade of the sewer will determine the velocity of the flow of the sewage,

and hence the capacity of the sewer to dispose of the gathered storm water.

It is very difficult to estimate the amount of ground water to be provided for. In some cases there may be considerable water for a short time and but very little afterwards.

Where the sewer intercepts a water bearing stratum the flow may be not only considerable but constant.

Sewers are rarely built large enough to dispose of the most rapid falls of rain. A certain depth per hour is assumed as reaching the sewers and the sewers are designed to dispose of the amount of water falling on the sewered area at the assumed rate of rainfall over the whole surface.

The depth of rainfall assumed as reaching the sewers varies under the different circumstances from half an inch to one inch per hour. In exceptional cases rain has fallen at four or five times that rate.

Several different formulas have been proposed for determining the size of sewers. The following are some of these:

Julius W. Adams formulas.*

$$D=\sqrt[6]{\frac{Q\,L}{1542H}} \qquad [1]$$

in which D=diameter of sewer in feet.
Q=cubic feet per second to be provided for.
L=length of sewer.
H=rise for length L.

$$\log D=\frac{2\log A+\log N-3.79}{6} \qquad [2]$$

in which D=diameter, in feet, of sewer.
A=acres to be drained.
N=length in feet in which the sewer falls one foot.

These formulas are on the basis of one inch of rain per hour, one-half of which reaches the sewer within the hour.

*Sewers and drains for populous districts, pp. 47—68.

Thomas Hawksley's Formula, used in the main drainage of London:

$$\text{log. diameter of main (in inches)} = \frac{3 \text{ log. } A + N + 6.8}{10} \ldots . [3]$$

A=acres drained.
N=length in which the sewer falls one foot.

This is on the basis of one inch of rain per hour.

Knowing the amount of storm water to be provided for, the size of the sewer may be determined by the formulas given in a former chapter.

The Burkli-Ziegler formula for the probable amount of storm water is:

$$Q = 1.25\, c\, r \sqrt[4]{\frac{S}{A}} \ldots\ldots\ldots\ldots\ldots\ldots [4]$$

Q= cubic feet of water reaching the sewers in one second.
c= a coefficient depending upon the nature of the surface and varying from 0.25 in rural districts to 0.60 for paved streets, average 0.50.
r=cubic feet of water per second falling on an acre.
S=the number of feet fall of the surface in 1000 feet.
A=area drained in acres.

Forms of Sewers.—For sewers flowing half full, or more, the circular section is best. But when, as is usually the case with combined sewers, the ordinary flow of sewage fills but a very small part of the cross-section of the sewer, it is best to so form the cross-section as to concentrate the stream and give it more depth. The form usually adopted is egg-shaped with the small end down.

Materials.—Sewers may be built of brick, terra cotta, stone or concrete, or a combination of these materials.

They are usually built of brick laid in hydraulic cement. The bricks should be burned hard and laid with full joints.

Baldwin Latham gives the following formula for determining the proper thickness of brick sewers:

$$\frac{d\,r}{100} = \text{thickness of brick-work in feet.}$$

d=depth of excavation in feet.
r=external diameter of sewer in inches.

The details of the construction of brick sewers are given in the specifications.

Catch Basins.—The storm water from the street should be first received in a "catch basin," where the dirt and debris from the streets can settle and not be carried into the sewer. They are usually placed at the street corners, near the junction of the gutters.

Man-Holes—These are similar to those on the separate sewers, Plates VII and VIII. They start from the springing line of the upper arch of the sewer.

It frequently happens that storm water conduits can be built separate from the sewers at a less cost than to build a combined sewer. The storm water conduit need not be as deep as a sewer. It can be discharged into the nearest natural water course, and this often very much shortens the necessary length of the large conduit.

Where sewage must be pumped the separation of the storm water from the sewage is a necessity if economical working is desired.

CHAPTER XIV.

SEWAGE DISPOSAL.

One of the most difficult problems presented for solution to the Sanitary Engineer to day, is that of sewage disposal. How to effectually dispose of the solid and liquid wastes in any community so that they will be neither offensive or dangerous to any one is a question of growing importance. The rapid increase in population of our cities and villages swells the flood of sewage which is poured into the streams, polluting the natural sources of water supply, while the demand for pure water is of necessity rapidly increasing.

In the older countries of Europe the pollution of water courses by sewage has forced itself upon the attention of government officials, and stringent laws have been passed to protect the purity of streams. In this country the time is not far distant when the pollution of streams and lakes by sewage will need to be forbidden by law, or in many localities pure drinking water in any considerable quantities will not be obtainable.

In many cases there is no available outfall for the sewage and the question of its disposal comes up at once with the inception of sewer projects.

Of the various methods of sewage disposal those which have been tested on any considerable scale may be classed as follows:

1. It may be emptied into a stream or large body of water.

2. It may first be clarified by straining, by subsidence, by filtration, by chemical processes or by a combination of these and the effluent turned into a stream or body of water.

3. It may be applied to the soil, as in intermittent downward filtration, broad irrigation, or subsurface irrigation.

Dilution.—When sewage is turned into a stream of considerable size the disappearance of the sewage is due to several causes. The sewage is diluted by the large amount of water into which it is discharged, some of the organic matter becomes food for aquatic plant and animal life and some is destroyed by oxidation, and the remaining solid particles are deposited along the bed and banks of the stream. So long as the amount of sewage is small in comparison with the volume of water this method may be admissable, but it is in use in scores of cases where it ought not to be.

Rivers and lakes often become so polluted by sewage as to become a serious menace to the health of cities on their banks. The Chicago River and Lake Michigan at Chicago, and the Cuyahoga River and Lake Erie at Cleveland are examples of this.

Subsidence.—When sewage is partly purified by subsidence the sewage is collected in tanks and allowed to stand until the solids are deposited and then the water is drawn off. Although somewhat less objectionable, the effluent water is charged with impurities and is still unfit to be turned into the natural water courses.

Filtration.—Filtration is sometimes resorted to and the sewage is passed through filters of various sorts. This separates more of the solids than can be obtained by subsidence, but the effluent is still unfit to be turned into the streams.

Chemical Processes.—Chemical processes have been extensively used. In these some chemical solution is mixed with the impounded sewage, which precipitates not only the solid matter but also a part of the substances held in solution. There are scores of these patented processes—too many to even name within the limits of this chapter. The solid residuum or "sludge" is used as a fertilizer. The hope that the "sludge" would be of great value as a fertilizer has not been realized and very little profit can usually be obtained from this source.

The effluent water is far from pure and frequently decomposes after being turned into a creek or river. This method

might be used advantageously where the effluent passes into the sea or large tidal rivers, where the water is not used for water supply.

Application to the Soil.—Filtration through the soil, both upward and downward has been used. Intermittent downward filtration has worked quite successfully. By this method the sewage is turned on to ground which has been thoroughly underdrained. The sewage is filtered by passing through the soil and much of the organic matter is destroyed by oxidation and nitrification.

Separate filtering beds are prepared so that they may be used alternately. The effluent water is quite pure if the filter beds are properly made and kept in good condition. The amount of ground necessary and the depth of the under drains depend upon the character of the soil.

Where sufficient suitable land can be procured broad irrigation is the most satisfactory method of sewage disposal.

The soil should be loose and thoroughly underdrained. Compact clay is not suitable for a sewage farm without special treatment for breaking up and loosening the subsoil.

The amount of sewage per acre which can be disposed of varies with the nature of the soil, and its special preparation for sewage disposal. In practice one acre of land has been used in broad irrigation for disposing of the sewage of from 50 to 500 persons.

CHAPTER XV.

THE PURIFICATION OF SEWAGE BY APPLICATION TO THE SOIL.

It is still an open question whether water which has been contaminated with sewage may be so thoroughly purified as to be entirely safe for culinary uses.

So far as chemical purification is concerned there is no doubt it can be accomplished by filtration through the soil under favorable conditions. Whether the effluent can be so purified by this means as to contain no trace of the bacteria which are supposed to incite various zymotic diseases, the water having been previously contaminated with them, is still in dispute by eminent authorities who have labored in this field. It is well known that the purest of natural waters, as regards organic matter, are those which have undergone prolonged filtration through the soil. Our knowledge of the causes which influence the purification of sewage when applied to land, either in broad irrigation, intermittent downward filtration or subsurface irrigation is rapidly extending, however, and this is a field of such promise as to justify a reference more at length to some of the later achievments and conclusions concerning this method of purification.

The impurities with which sewage is charged consist mainly of different organic compounds in various stages of decomposition. It is not practicable, or in fact desirable, to prevent the decomposition of these organic compounds. With the exception of the small portion which may be consumed as food by animal life, they must be resolved into their elementary substances before they can again be utilized by plant life or otherwise

rendered innocuous. It is, however, practicable to so control the conditions of decomposition that it shall become inoffensive and the resulting compounds shall be fixed and rendered harmless by some surrounding medium. The soil is a medium which not only renders these products innocuous but also favors a mechanical separation and aeration very conducive to the rapid disintegration and absorption of the putrescible matters contained in the sewage.

In the report of the Select Committee on the Metropolis Sewage it is stated that, "No efficient artificial method has been discovered to purify, for drinking and culinary purposes, water which has once been infected by town sewage. By no known mechanical or chemical means can such water be more than partially cleansed; it is always liable to putrefy again. Processes of filtering and deodorization cannot, therefore, be relied upon to do more than mitigate the evil. Water which appears perfectly pure to the eye is sufficient, under certain conditions, to breed serious epidemics in the population which drinks it. Soils, however, and the roots of growing plants have a great and rapid power of abstracting impurities from sewage water and rendering it again innocuous and free from contamination."

The process of purification of sewage by filtration through the soil is similar to that of burning up or oxidizing the organic matter leaving only a harmless mineral residue, which is soluble and passes off in the effluent, leaving the filtering medium, when properly managed, undiminished in efficiency. The application of sewage intermittently serves to increase the amount of oxidation similarly to opening the draft of a furnace.

The changes produced by wet oxidation, however, are not the same as those produced by heat, there being intermediate processes. In the former the nitrogen of the organic matter first combines with the hydrogen to produce ammonia which, upon uniting with oxygen, produces nitric acid. This, in turn, combines with potash, soda, lime or some other base present in the sewage or in the soil to produce a soluble nitrate. The extent to which this sequence of combinations has proceeded is a

measure of the degree of purification of the sewage. The larger the amount of nitrates in the effluent, therefore, and the smaller the amount of ammonia, the more completely has the organic matter of the sewage been destroyed. Later investigations have shown that the earlier of these processes depend on the presence of living organisms.

The Influence of the Bacteria of Nitrification.—The following interesting facts concerning nitrification or the conversion of ammonia and the nitrogen of organic matter into nitric acid in the soil, upon which process the purification of sewage largely depends, were given by Mr. R. Warrington, in a paper read before the Society of Arts in 1882.*

"Diluted solutions of urine or of ammonium salts containing the essential constituents of plant food, undergo no nitrification, though freely exposed to the air, if only they have been previously boiled and the air supplied to them is filtered through cotton wool. If to such sterilized solutions a small particle of fresh soil is added no action at first appears but after awhile active nitrification sets in and the ammonium or urea is converted into a nitrate. For the production of nitric acid it is necessary that some base should be present with which the nitric acid may combine. The action proceeds best in the dark. When a solution has thus undergone nitrification a drop of it suffices to induce nitrification in another solution, which, unless thus seeded would have remained unchanged. Boiling the soil, or the solution that has nitrified, entirely destroys its power of causing nitrification. The presence of antiseptics also prevents nitrification. Lastly, nitrification is confined to the same range of temperature which limits other kinds of fermentation. The production of nitrates proceeds very slowly near the freezing point, but increases in rapidity as the temperature rises, reaching its maximum of energy, according to Schlaesing and Müntz, at 99° Fahr. At higher temperatures the rate of nitrification rapidly diminishes, it almost ceases, according to the same observers, at 122° Fahr., and at 131° Fahr. no change occurs. It thus appears that nitrification can only be produced in the presence of some nitrified or nitrifying material, and the whole course of action is limited to the conditions suitable for the activity of a living ferment. The French chemists claim to have isolated the ferment by systematic cultivation. It belongs to the family of *Bacteria*.

The purifying action of the soil on sewage is probably due to three distinct actions: 1. Simple filtration, or the separation of suspended matter. 2. The precipitation and retention by the soil of ammonia and various organic

* The Treatment and Utilization of Sewage—W. H. Corfield, 1887.

substances previously in solution. 3. The oxidation of ammonia and organic matter by the agency of living organisms.

The last mode of action is undoubtedly the most important, as without oxidation the sewage matter must accumulate in the soil and the filter bed lose its efficacy. The filtering power of a soil will depend entirely on its mechanical condition. The precipitating power of soil, is on the other hand, a chemical function, in which the hydrated ferric oxide and alumina and the silicates of soils probably play an important part. The oxidizing power of a soil will depend partly on its mechanical, partly on its chemical and partly on its biological condition.

It was formerly supposed that the oxidizing power of a soil depended solely on its porosity, oxidation being assumed to occur by simple contact with air in the pores of the soil. We now know that a porous medium is by no means essential for nitrification; sewage may, indeed, be nitrified in a glass bottle, or when passing over polished pebbles. Though, however, porosity is by no means essential to the nitrifying power of a soil, it is undoubtedly a condition having a favorable influence on the rapidity of the process; a porous soil of open texture will present an immense surface* covered with oxidizing organisms and generally well supplied with air requisite for the discharge of their functions. It is doubtless owing to this fact that nitrification takes place with so much greater rapidity in a soil than in a liquid. The sewage will itself supply the substances required for the nourishment of the oxidizing organisms * * * * The organisms which effect the oxidation of organic matter are abundantly present in surface soils but are probably absent, or nearly so, in subsoils. In surface soils they will probably be abundant in proportion to the richness of the soil in organic matter. Sewage also contains the organisms necessary

* In order to bring out the point here spoken of by Mr. Warrington a little more prominently the author made the following experiment, which may be of interest:

Fifty cubic centimeters of ordinary screened mason's sand, of a fineness of 40 grains per lineal inch, were placed in a chemist's burette, having first been thoroughly freed from moisture by continued drying at a temperature of about 225°. Water was then introduced into the burette from below by aspiration, so as to facilitate the expulsion of contained air until the voids were entirely filled and the amount of water introduced carefully noted. The burette was then opened below and the excess of water over that naturally adhering to the particles of sand was allowed to drain off. From the facts noted the following computations were made:

The total air space in the dry soil was 36 per cent. of the cubic contents. The water adhering to the particles of soil was 18 per cent. of the cubic contents. The total superficial area of the particles of soil for each cubic foot was 2,200 square feet. The water adhering to the particlest of soil for each foot in depth was equivalent to a film of water 1-1000 inches thick and 2,200 square feet in area. Since the purifying agencies within the soil and its contained air have been proved to be active to a depth of at least three feet we may assume that the surface of sewage which is exposed to the action of these purifying agencies is approximately 6,600 times greater when sewage is applied to the soil intermittently than when it is simply impounded over the same area.

for its own destruction, and under favorable conditions these may be so cultivated as to effect the purpose."

Later investigations concerning the function of living organisms in the purification of sewage lead to the conclusion that they increase in numbers wonderfully when sewage is applied to soil originally quite deficient in organic matter, the conditions thereby being rendered favorable to their increase in proportion as their presence becomes needful to the purification of the organic substances supplied. This is shown in the experiments of the Massachusetts Board of Health, quotations from which are to be found farther on.

It also appears from experiments carried on at the model farm at Rothamsted, under Messrs. Lawes & Gilbert. and elsewhere, that these organisms are decidedly more numerous and active near the surface of the ground and their action under ordinary conditions is said to cease at a depth of about three feet and to be very uncertain below a depth of twelve or fifteen inches.

In view of these conclusions it appears that so far as the action of these organisms is concerned it is unnecessary to prepare intermittent filtration beds as deep as was formerly thought advisable, and Dr. Frankland has stated* that whereas in the Rivers' Pollution Report he had recommended 6 feet depth of earth for intermittent filtration he now had reason to believe that two feet would be equally effective.

These facts are also substantiated by the rapid purification which sewage undergoes when supplied to the soil immediately below the surface as in subsurface irrigation.

A test made in one of the experimental filtration tanks of the Massachusetts State Board of Health, to determine the distribution of bacteria at different depths gave the following results:

* Van Nostrand's Engineering Magazine, November, 1886.

NUMBER OF BACTERIA FOUND IN ONE GRAMME OF SAND AT VARIOUS DEPTHS.

Distance from Surface.	May 22, 1889.	Distance from Surface.	May 22, 1889.
0 to ½ inch	1,760,000	5 inches	63,400
½ to ¾ "	105,000	8 "	30,700
1¼ to 1½ "	207,200	12 "	34,100
2 inches	60,200	19 "	12,300
3 "	111,300	60 "	4,100

The most rapid decrease is in the upper few inches.

Koch says that the micro organisms in the soils he has examined diminish rapidly with the depth and at the depth of a metre the soil is nearly free from bacteria.

"It has been found that if one starts with an artificial filter bed of perfectly clean sand, containing no bacteria, and floods it with dirty water the water which comes through for the first few days, and for a much longer time if the weather be cold, will be but little, if at all, purified. Its coarser suspended particles may have been caught in the sand pores, and so it may be clearer, but its dissolved organic matter and its bacteria may not be at all diminished. Indeed, for some time, strange as it may appear, the numbers of the bacteria may have largely increased. In fact, it appears that the pores of such a fresh sand-filter with the organic matter suspended in the water, form a most excellent breeding place for bacteria.

This seems discouraging, but let the experiment go on, and after a while if the dirty water has not been forced through the sand too fast, it will be found that the number of living germs which come out in the water at the bottom is growing steadily smaller and finally the water may be nearly or quite germ free. Now, if the chemist exposes some of the filtered water to his delicate tests he may find that the organic matter which was in solution in the water at the top has already diminished or entirely disappeared, being represented, perhaps, by nitrogen, which has formed harmless combinations with oxygen.

It really seems as if the more of the living, growing bacteria you had in the upper layers of your filter bed, the freer became the water below both in bacteria and organic matter. This is, in fact, the case. We do in this experiment what nature does on a larger scale—make the bacteria fight the organic matter and themselves.

But how is this effect produced? The bacteria are so small that hundreds of them could easily pass abreast through the smallest spaces between the sand particles. What holds them back?

When the sand particles at the upper portion of these filter beds have been carefully examined it has been found that they are, after a few days, completely encased in a slimy gelatine-like envelope, formed of a material which many bacteria secrete around themselves as they grow. This bacteria-formed slime more or less fills the pores of the filter bed, enclosing the bacteria themselves and the sand particles, and catches and holds fast on its sticky surfaces not only suspended matter of various kinds but the new bacteria which come onto the filter and start to work their way down through its pores. Here, many of them, like good prisoners, set to work to make the best of the situation, and if their nature permits, turn to and help to make more of this trap-slime to capture the next comers.

Many of the enlarged germs, however, do not form this material and these may die in large numbers where they lie. On the other hand, this enforced detention is simply paradise for many of the germs. Here they are resting at ease in a slimy confinement, with boundless supplies of just the food they want slowly trickling by them. The food is dead organic matter, which the average bacterium simply dotes on and reeks little whether it be in solid form or in solution, so there be enough of it. At it he goes then, and by some wholly inscrutable phase of the life power in his tiny body, asunder fall the atoms which have once been parts of animal or plant. That part which the tiny life spark needs to keep its glow agoing is appropriated. The rest he leaves, its atomic cravings unsatisfied, and only too ready to succumb to the wiles of the ever amorous oxygen, which must always be present in a perfectly acting filter bed.

The slowness and the intermittent character of natural soil filtration is a very important matter in the accomplishment of perfect results, because in the times between rains the soil pores have a chance to become filled with stores of oxygen in the form of ground air.

Behold now the secret of this marvelous alembic into which may go things most foul and harmful, but out of which comes the very type of cleanliness—clear spring water. It is largely the bacteria, living, growing, multiplying, following their life impulses silently and unseen, each after its kind, which, supported by the active agency of the oxygen, bring about this beneficient result."—*Prudden, in Drinking Water and Ice Supplies.*

Nitrification.—

"The conditions influencing nitrification have been for the most part already mentioned incidentally, We may, however, advantageously recapitulate them.

"(*a*) The formation of nitrates appears to require, or to be facilitated by an *elevated temperature*, and goes on most rapidly in hot weather and in hot climates.

"(*b*) According to Knop, ammonia that has been absorbed by a soil suffers no change so long as the soil is dry, but when the soil is moistened nitrification quickly ensues. *Water* thus appears to be indispensable in this process.

"(*c*) An *alkali base or carbonate* appears to be essential for the nitric acid to combine with. It has been thought that the mere presence of potash, soda and lime favors nitrification, 'disposes,' as is said, nitrogen to unite with oxygen. Boussingault found, however, (*Chimie Agricole, III, 198*) that caustic lime developed ammonia from the organic matters of his garden soil without favoring nitrification as much as pure sand. The caustic lime by its chemical action, in fact, opposed nitrification, while pure sand, probably by dividing the particles of earth and thus perfecting their exposure to the air, facilitated this process."*

Absorptive Power of the Soil.—The results of fifty-one experiments by Dr. Lissauer to determine the absorptive power of soils point to the following conclusions, among others:

"(*1*) The liquid entering the pores of the soil displaces the air or liquid previously present, forcing the former upwards into the atmosphere, and the latter downwards into the subsoil or effluent water.

"(*2*) In order that the effluent water may not be directly polluted by the sewage liquid, the maximum supply of the latter must not be more than can be taken up by the pores of the soil.

"(*3*) Dry, loamy soil absorbs more than peaty soil and gives up less, whilst dry, sandy soil, on the contrary, absorbs less and gives up more. Consequently a loamy soil, though it absorbs a large quantity of liquid, can seldom be irrigated, whereas a sandy soil, though it absorbs but little may often be irrigated.

"(*4*) The looser the soil the easier water courses are formed in it, and therefore the less can its maximum power of absorption be approached, otherwise the sewage liquid might penetrate the subsoil before the whole of the ground had been saturated.

"(*5*) In order therefore that the effluent water may be protected from pollution it is especially necessary that the absorptive power of the soil should be known, but the determination is of no value unless it be made in a sample in which the natural position of the particles of earth has been undisturbed."

The Function of Nitrates.—It should be stated in this connection that the nitrates, which are the product of the nitrification or oxidation of the organic matter contained in sewage, supply nitrogen in its most available form as plant food.

* Johnson—How Crops Feed.

"Experiments in artificial soil and in water culture show not only that nitrates supply nitrogen to plants, but demonstrate beyond doubt that *they alone are a sufficient source* of this element, and that no other compound is so well adapted as nitric acid to furnish crops with nitrogen." *

In the absence of plant life, a portion of these nitrates being very soluble, passes away with the effluent in a harmless form.

The Committee of the British Association, on the Treatment and Utilization of Sewage, made an estimate of the amount of nitrogen recovered in crops on Breton's farm, near Romford, with the following results:

"Of every 100 parts of nitrogen distributed over the farm during the twelve months, 10.67 parts, or about one tenth, were found in the effluent water; 41.76 parts, or about four tenths, were recovered in the crops, making together about half; and 47.57 parts were unaccounted for." †

It was subsequently ascertained by analysis of the soil that the nitrogen in the soil had largely increased.

Experiments of the Massachusetts State Board of Health.—By far the most systematic experiments upon the filtration of sewage through the soil, which have come to the knowledge of the writer, are those being conducted by the Mass. State Board of Health, at Lawrence, Mass. These experiments have been conducted so carefully and thoroughly and over such a wide range of conditions that they are of particular interest. The results of the experiments are contained in the Report of the Board on Purification of Sewage and Water, 1890, from which the following information is gathered.

"The filtering grounds comprise about two-thirds of an acre. Upon them are ten tanks, circular in plan, about 17 feet in diameter and allowing for material to be filled in 5 feet deep. From the lowest point in the bottom of each tank a 2-inch pipe conveys the drainage to a flume within a building, whence the effluent is taken for analysis and examination.

The tanks were filled with different materials, as follows: No. 1, very coarse, clean mortar sand; No, 2, very fine, nearly white sand; No. 3, peat; No. 4, river silt; No. 5, brown garden soil, well manured; No. 6, 7 and 8 were filled with 3 feet, 8 inches of coarse and fine sand, 10 inches, of yellow, sandy

* Johnson—How Crops Feed, p. 90.

† Corfield, on the Treatment and Utilization of Sewage, p. 419.

loam and 6 inches of brown soil; No. 9, very compact, sandy, hardpan of clay, sand and gravel, covered with 9 inches of brown soil.

The sewage used in the experiments was taken from a main sewer draining a portion of the city. Apparatus was erected for measuring the sewage and the effluent, and biological and chemical analyses of both were made daily. The sewage was applied intermittently at intervals of one or more days."

In the twentieth Report of the Board we find the following statements regarding the general results which have been obtained:

"Sewage can be much more efficiently filtered through open sand, than through sand covered with soil. Very fine material, like dust, in the upper layers of a filter, prevents free access of air, and when wet, may exclude air so completely as to render purification impossible. With soil or sand containing dust at the surface, periods of intermission in the application of sewage may be made so long that the surface, becoming dry, may allow air to enter, and a high degree of purification may result; but the quantity of sewage that can thus be purified is very much less than when the upper layers of the filter are composed of open sand, through which the sewage will rapidly disappear and will leave room for air to enter and come in contact with the thin laminas of liquid covering the particles of sand.

The experiments of last winter show that intermittent filtration can be carried on upon a bed of coarse sand through the coldest weather, when the beds are exposed to snow, but that the efficiency of the beds is much reduced by such exposure and the consequently low temperature of the sewage passing through the sand. By protecting the beds so that snow cannot fall upon them and reduce the temperature of the applied sewage to near the freezing point, the experience of the present winter so far, indicates that very complete purification may be continued through very cold weather by applying the sewage intermittently at the temperature at which it ordinarily comes from the sewer. The experiments of last winter show that, when the beds are exposed to the snow intermittent filtration may be carried on through the moderate weather of winter, alternated by continuous filtration during the colder period."

"Four tanks, filled with clean, coarse mortar sand from the same pit, were subjected to different conditions. One of these was exposed to the cold and snow, and, although, it received sewage daily and removed about two-thirds of the impurities of the sewage during the very cold months of January, February and March, when filtering at the rate of 30,000 gallons per acre per day, it is evident, from the results in the other three tanks, which were not exposed to frost, that the sewage entered and passed through but a fractional part of the area of this tank, and the result is as poor as if a much larger quantity had been applied to a like area not obstructed by frost.

The three other tanks were supplied with sewage at the rate, respectively, of 30,000, 60,000 and 120,000 gallons per acre per day, and until nitrification commenced, in the latter part of March, periods of forty-one, thirty-one and twenty-seven days, respectively, the ammonias indicated that 97, 94 and 80 per cent. of the impurities of the sewage were removed.

Nitrification began to increase in all of these tanks between March 26 and 30, when the temperature of the effluent was at 39° or 40°. In the course of three weeks the nitrates had increased from 0.025 parts in 100,000 to 0.250 parts, after which they increased much more rapidly, and nitrification was most complete from May 6 to 10, or six weeks after it began, the nitrates then amounting to from 2.5 to 3.0 parts per 100,000.

During the increase in nitrification the ammonias also increased for a time, and became nearly one-third of those of the sewage; but generally, before the nitrification reached its height the ammonias decreased rapidly, until they became one-half of 1 per cent. and ½ per cent. of those of the sewage. The rapidity of purification, as shown by the decrease in ammonias, was greatest in the tanks which had received the most sewage and had the greatest amount of nitrogenous matter stored in them,—the effluent from the sand which had received the least sewage being more than a month later in reaching its condition of greatest purification. The filter receiving sewage at the rate of 120,000 gallons per acre per day gave an effluent for three months after purification, resulting from nitrification, was established, in which the ammonias were less than 1½ per cent. of those of the sewage. Upon increasing the amount filtered to 180,000 gallons per acre per day the ammonias increased, but for the next four months averaged less than 2 per cent. of those of the sewage.

One of the filters receiving sewage at the rate of 60,000 gallons per acre per day for seven months after purification was established, gave an effluent of nearly constant quality, having one-half of one per cent. of the ammonias of the sewage, the free ammonia averaging 0.0012 parts and the albuminoid ammonia 0.0105 parts in 100,000 parts, showing less organic matter than many of the drinking waters of the State.

The other filter of the same material, receiving 60,000 gallons of sewage per acre per day, gave an effluent for three months after purification was established, having between 1 and 2 per cent. of the ammonias of the sewage, but in the next two months these increased to 6 and then to 10 per cent. This increase was due in part to the imperfect distribution of the sewage over the whole surface, which being corrected, the percentage of the ammonias decreased and averaged for December 4½ per cent. of those of the sewage.

The tank of this material, which has filtered at the rate of 30,000 gallons per acre per day, was as stated, a month later than the others in reaching an established condition after nitrification became active. For the following six weeks

the ammonias of the effluent were but one per cent. of those of the sewage and the nitrates were a little more than one part per 100,000."

In each of the experiments above recorded sewage was applied intermittently at intervals of one or more days, and disappeared from the surface in a few minntes or in a few hours. The results obtained by intermittent downward filtration in the above experiments are very favorable and in striking contrast to those obtained by continuous filtration as will be seen by the following extract from the report. These experiments were made with a tank which received 30,000 gallons per acre per day in the experiments on intermittent filtration and through the same material—coarse sand.

"At the end of this time the outlet was closed and the tank filled with sewage, and for the next four months the surface of the sand was kept covered with sewage, and the outlet was opened each day sufficiently to allow the regular quantity at the rate of 30,000 gallons per acre per day to flow out. The filter was thus changed from the condition of intermittent filtration to that of continuous filtration. During the first month the nitrates were reduced from one part per 100,000 to less than 0.01 part, at which they continued for the remaining three months. The ammonias rose in the first month from 1 per cent. to 1½ per cent. of those of the sewage. In the second month they became 31 per cent. and at the end of the fourth month were equal to those of the sewage.

This shows distinctly the radical difference in result between intermittent and continuous filtration. In intermittent filtration the nitrification was active and, as shown by the ammonias, 99 per cent. of the organic impurities were removed, while in continuous filtration the nitrification ceased, and the same sand, filtering the same quantity of sewage, stored impurities for a time, but finally poured out an effluent quite as impure as the applied sewage."

The biological analyses, an account of which appears below, are also of particular interest as furnishing an index of the degree to which it may be possible to free sewage from the contamination of disease germs by the methods adopted, and also as corroborating the statement previously made that the bacteria of nitrification remain in the upper strata of the soil.

"From these open sands the number of bacteria in the effluent has, during the past six months, varied from 2 per cent. to a very small fraction of 1 per cent. of the number of bacteria in the sewage.

A filter of very fine sand, after filtering an amount equivalent to 8,600,000 gallons of sewage upon an acre, filtered at the rate of 12,000 gallons per acre per day, giving an effluent in which the organic matter, shown by the loss on ignition, was but 3 per cent. of that of the sewage, and the nitrogenous matter, as shown by the ammonias, was but one quarter of 1 per cent. of that of the sewage.

The loss on ignition was	0.5000 parts in 100,000
The free ammonia........................	0.0002 parts in 100,000
The albuminoid ammonia was..............	0.0062 parts in 100,000
The nitrates were.........................	0.7000 parts in 100,000

At the same time the bacteria of the sewage amounted to 591,000 in a cubic centimeter, while those of the same quantity of effluent amounted to 2, and these may have come from the air while collecting the sample. By both chemical and bacteriological analysis this effluent from sewage has less organic impurity than the water of Lake Winnipiseogee, and contains but little more nitrogenous organic matter than city water filtered through the same material a year ago. This sand stored much impurity in the winter. Nitrification began actively in June, and for three months appeared to be active in removing stored impurity, so that purification did not approach the completeness given above till September, since which time it has steadily grown more complete."

"Garden soil makes a very poor filter. Upon applying sewage intermittently to a body of garden soil five feet deep, after the first month the organic impurities increased continually for eight months, until the effluent became more impure than the applied sewage. There had then been applied 24,000 gallons, the equivalent of 4,800,000 gallons on an acre, and it was then being applied at the rate of 10,000 gallons per acre per day. The daily quantity passing through has since been reduced to 5,000 gallons per acre per day, and the quality of the effluent has somewhat improved, but still contains as much nitrogenous matter as crude sewage."

"A very few vegetable organisms that can be identified by the microscope have been found to occasionally pass through the coarser filters, but in general none come through. A few animal forms have been found in the effluent, but these may grow in the underdrains and outlet pipe. The question remains to be settled, whether any animal or vegetable microscopic organisms live to get through the filters of finer material at the rate which sewage has been filtering. Of the still more minute organisms, the bacteria, we found that soon after sewage was first applied to the tanks they came through in great numbers, but became reduced in number and during the later winter and spring months amounted to two per cent. and less of those of the applied sewage, but after nitrification commenced they decreased rapidly, and continued through the summer, in many cases less than one hundred, and in some less than ten, while the number in the same quantity of applied sewage was about a million."

"The experiments made to the present time show that the number of bacteria in the sand decrease very rapidly from the surface downward. In the finer sands they nearly or quite disappear before the bottom is reached. * * *

We have reason to hope that filters may be so made and managed that all disease germs may be, with certainty, removed."

The Influence of Temperature.—Considerable discussion has arisen as to the practicability of sewage disposal by application to the soil during the winter months in northern latitudes.

In the investigations of the Massachusetts State Board of Health previously quoted it was determined that:—

"During the cold months the nitrification was about nine-tenths as complete as the mean for the year and that the loss on ignition and the ammonias of the effluent were about one-fifth greater percentage of the amounts in the sewage producing the effluent than for the year. This is in all respects a very satisfactory result of continued purification by this filter (coarse sand) during the winter."

The following abstract from the report of the Committee of the British Association is also of interest:

"A comparison was made in January, 1871, during severe frost, of the results obtained in the purification of sewage at the three following farms:—Breton's farm, near Romford, Biddington farm, Croyden, and Norwood farm. It was found that in the latter two cases, where the sewage was passed over the land in the catch water system, it was not satisfactorily purified, the nitrogen escaping in the effluent water being only partially in the state of nitrates and nitrites; while at Breton's farm, where this sewage passes through the soil, the farm being in effect a large filter bed (1) oxidation goes on in winter as well as in summer, and almost all nitrogen lost is lost in an oxidized and inoffensive form; and (2) this loss is very slightly greater in winter with a very strong sewage than in summer with a weaker one."*

"There is one point which I think deserves consideration in connection with the question of the winter disposal of sewage upon land, and this is the temperature of the sewage. * * * * While it is probable that the coldest sewage may be disposed of upon land in winter in this climate, such disposal may be more confidently advised where the sewage is warmer, and in seeking for precedents it is desirable to know the temperature of the sewage as well as the severity of the winters." †

* Treatment and Utilization of Sewage—W. H. Corfield, p. 372.

† F. P. Stearns in Transactions of the Am. Soc. C. E., January, 1888.

Aeration of the Soil.—The effects of a lack of air in the interstices of the soil are apparent from the experiments on continuous filtration previously cited. At the time the experiments were in progress the outlet pipe from the tank was trapped so that no air could enter the tank from below. There is reason to believe that the lack of nitrification in continuous filtration is due to the lack of oxygen. In order to substantiate this fact experiments on filtration were conducted at the experiment station at Lawrence, Mass., in a tank filled with coarse sand and arranged so that the quantity of air admitted to the tank could be controlled by an aspirator. The conditions otherwise were the same as in intermittent filtration. Sewage was applied intermittently through a funnel and stop cock and distributed over the surface by a perforated plate. Nitrification ceased soon after the supply of air was stopped and the effluent was little better than the sewage. Subsequently the cock by which sewage was admitted to the tank was left open, thus ventilating the top of the tank. The condition of the effluent did not improve. Upon removing the cover of the tank entirely the condition was but little improved by reason of the tank being clogged with organic matter which had not been oxidized during the time that the air was excluded. Upon removing half an inch from the surface of the tank and applying an aspirator below, drawing a gallon of air each four minutes, the effluent rapidly improved and in two weeks nitrification became complete. During this time the air of the tank contained almost as much oxygen as outside air.

"This underground air is, however, almost as ceaselessly in motion as is that in which we move. Whenever the ground gets heated it streams out of the myriad pores of the surface into the sunshine. When the ground cools, back through the same pores rushes the aërial air. Every wind which sweeps the surface moves the air beneath in great volumes. With every rain it is driven deeper down. The movements of this buried atmosphere are slow, because it must find its way around the myriads of soil particles which block its course. But it is of great extent and of great importance "—*Prudden, in Drinking Water and Ice Supplies, 1891.*

Effect of Different Soils.—In the experiments at Lawrence it was found that :—

"With the gravels and sands, from the coarsest to the finest, nitrification takes place in all, when the quantity of sewage is adapted to their ability, and the surface is not allowed to become clogged by organic matter to the exclusion of air. With fine soils, containing in addition to their sand grains, two or three per cent. of alumina and oxide of iron and manganese, and six or seven per cent. of organic matter when only six inches in depth, resting upon fine, sandy material, they retain water so long that the quantity that can be applied is so small, and the interval in which this must settle and dry away to allow air to enter the filter is so long, that the amount of sewage that can be purified is very small. When the quantity applied is adapted to its ability such a filter may give an excellent effluent, quite free from bacteria."

There is reason to believe that the effect of simple mechanical filtration through the soil in the purification of sewage has been over-estimated.

Where compact and retentive surface soils are found on a more open subsoil a much greater quantity of sewage can be satisfactorily purified by distributing it beneath the surface through tile drains with open joints as in subsurface irrigation. The application in this manner being more favorable to the admission of air through the comparatively impervious surface, especially after continued use.

In one of the experiments at Lawrence the capacity of the soil to purify sewage was increased threefold in this manner.

The average results of purification, at Lawrence, by various soils for periods of from three to eight months, mostly in the second year of filtration, are given in the following Table:

Character of Soil.	Gallons of Sewage per Acre per day.	Percentage the sum of Ammonias of Effluent was of the sum of Ammonias of the Sewage.	Percentage the number of Bacteria in the Effluent was of the number in the Sewage.
Coarse mortar sand	117,000	1.4	3.
" " "	60,000	0.4	0.02
" " "	55,400	2.5	0.19
Coarse and fine sand and fine gravel	42,600	0.5	0.08
Fine white sand	28,700	0.4	0.003
River silt, mostly fine sand	13,400	0.6	0.002
3 feet 8 inches sand and gravel 10 inches yellow sandy loam 6 " Brown soil	8,880	0.4	0.001

The several amounts per acre of sewage set opposite the different soils are the amounts they were found by experiment to be capable of purifying indefinitely.

The Table exhibits in a general way the superiority of the more open soils as to purifying large quantities of sewage and of the compact and more finely divided soils in removing living organisms.

Self Purification of the Soil.—Tank No. 1, in the experiments previously quoted, being constantly in use for nearly two years without any renewal of material or removal of sediment from the surface nitrified much more completely during the latter six months of the second year than during the corresponding months of the first year. The average percentage the nitrogen of the nitrates in the effluent is of the total nitrogen in the sewage being for 1888 44 per cent. and for 1889 65 per cent. It thus appears that the effectiveness of the filter considerably

increased. The quantity of sewage applied in each period varied but four per cent.

The facts previously cited as to the behavior of tank No. 1 upon the resumption of intermittent filtration after a period of continuous filtration indicate that impurities stored in the soil when the conditions are unfavorable for purification are, as soon as the proper conditions obtain, rapidly removed in the form of nitrates, and this without any period of rest.

This fact is of particular interest as effecting the disposal of sewage by filtration in winter. During short periods of severe winter weather the surface of filtering areas can be easily kept free from ice by the continuous application of sewage, which may be followed, as the weather moderates, by intermittent applications. The soil, storing in an inoffensive form, during the continuous filtration such impurities as cannot be oxidized, and subsequently when the conditions for intermittent filtration are favorable these stored impurities are oxidized and removed in addition to the oxidation of the sewage applied from day to day.

Experiments with intermittent filtration through gravel stones as large as beans, from which all particles of soil and sand have been washed out, have shown that when sewage is applied at the rate of 126,600 gallons per acre per day for a period of three months 98.5 per cent. of the organic matter was removed and the stones were as clean as at the beginning.

Practically then, it may be said that the soil can purify sewage for an indefinite time.

It is said that sewage has been applied to the Craigentinny meadows, near Edinburgh for the last 200 years.

Quantity and Concentration of Sewage.—From the above Table and the conditions essential to purification it seems fair to infer that the capacity of a soil filter to remove a certain amount of organic matter from sewage depends upon the degree of dilution. For instance, if the organic wastes from each person be mixed with 26 gallons of water the organic matter in the

sewage will be more readily removed than if mixed with 100 gallons. The degree of dilution for German, English and American cities, as indicated by the statistics of water consumption, is about 26, 35 and 100 gallons respectively. Excessive dilution must seriously interfere with the aëration of the filter upon which in a large measure depends its activity.

In like manner the dilution of sewage by storm water is a serious objection in filtration over limited areas where the application should be regular and substantially uniform in quantity.

The experiments at Lawrence have demonstrated that :—

"The preparation required to render filtering areas effective appears to be the introduction by the sewage of the particular organisms fitted to aid in this work, and their accumulation with a proper food supply, and other favorable conditions by which they become in time adapted to accomplish the most complete purification with the quantity of sewage received Any change in quantity or mode of application may disorganize this working colony and prevent the best results, until there is time for a re-adjustment adapted to the new conditions."

Influence of Area.—In the purification of sewage by intermittent filtration the object sought is ordinarily the application of the sewage to limited areas in the immediate vicinity of urban districts, where the value of land practically prohibits its application over areas sufficiently broad to favor its utilization in agriculture. In broad irrigation and utilization of the sewage, the areas available and the comparatively small quantity of the effluent make the process one much less likely to be disturbed by lack of proper management.

Experiments made at Paris upon the action of growing plants upon sewage during irrigation by M. Marie'-Davy gave the following results: Out of a supply of 5,000 to 6,000 cubic meters (tons) per hectare (2.5 acres) per month, only one thirtieth of the water supplied reached the subterranean drains. Vegetation consequently acts as a powerful upward drainage. The plants absorb the useful elements of the sewage and yield to the atmosphere, by evaporation, nearly the whole of the liquid which has served to convey them. Thus purification and agriculture utilization perfect each other.

It is said that at Dantzig during the hardest frost the sewage sinks beneath the surface coating of ice and snow and filters through the soil without causing any injury to the plants or trouble to the contractor.

Sewage Disposal at Pullman.—The sewage disposal works at Pullman offer a good opportunity for observing the success which may attend intermittent downward filtration in northern latitudes under somewhat unfavorable conditions.

The writer made a somewhat thorough examination of these disposal works during the past winter and also chemical analyses of the crude and purified sewage with especial reference to determining the feasibility of disposing of sewage by intermittent downward filtration in winter in this climate.*

Pullman is sewered by the Separate System. The population is about 11,000, the sewage from dwellings averages from 120 to 130 gallons a day per capita. The average number of gallons of sewage pumped per day in 1890 was 1,800,000. The balance of the sewage being the discharge from factories and possibly some ground water.

The sewage is pumped from the collecting well through a twenty inch cast-iron pipe to a sewage farm about three miles south of the city. At the farm end of this pipe the sewage goes into a receiving tank made of boiler iron which is set a few feet above the surface of the ground. Through the center of this tank there is a screen in an oblique position through the meshes of which substances more than half an inch in diameter cannot pass. The sewage passes through this screen and thence into the distributing pipes.

One hundred and forty acres of land have been thoroughly piped and underdrained for the reception and purification of sewage. Hydrants are placed at suitable intervals so that the distribution can be conveniently effected.

* I am indebted to Mr. Duane Doty, Editor of the Pullman Journal, Mr. —— Cox——, Assistant Manager, Mr. C. W. Campbell, Superintendent of the sewage farm, and Mr. Chas. H. O'Neil, Assistant Engineer of the sewage pumping station, for information and assistance.

PLATE XIX.

Filler Beds—Pullman.

Besides the area devoted to broad irrigation there are fifteen filter beds having a total area of 9½ acres specially prepared for intermittent downward filtration, to which the sewage is applied during a considerable portion of the winter, and whenever it cannot conveniently be applied to the surface under broad irrigation. These filter beds are underdrained by drains 12½ feet apart which converge at a man-hole.

The soil of the filter beds and of the entire farm is the rich alluvial prairie soil underlaid by a yellowish clay subsoil and poorly adapted for purifying large quantities of sewage, especially when the temperature is low. Nevertheless the results obtained here are very flattering.

I am informed that it is usual to apply the sewage of one day to about three of the beds, which are then allowed to rest for three days at least. About half of the filter beds are cropped each year with quickly maturing crops, such as plants to be transplanted. While the crops are growing no sewage is applied. Plate XIX is reproduced from a photograph of the filter beds taken at the time the examination was made, March 12th, 1891. The weather had been severe for about ten days previous and the temperature at 7 A. M. was 12° above zero. The beds are arranged, on ground slightly inclined, at different levels. Sewage is admitted to any of the high level beds at will through gate chambers, one of which is shown in the foreground. On the day previous the bed at the right was flooded with sewage to the depth of about 10 inches. This had nearly all disappeared beneath the surface, a thin sheet of ice one-fourth to one-half inch thick had formed on the impounded sewage, which, as the sewage sank beneath the surface was broken into small fragments. There is no accumulation of ice which interferes with the filtration of the sewage. The temperature of the sewage when applied to the beds, as taken in the carrier after being conveyed three miles underground at the season when the subsurface temperature as shown by observations is about at its lowest, was 51° F. The temperature of the effluent as taken in the man-hole to which the subsoil drains converge was 38° F.

The ~~latent~~ heat given up by the sewage during this fall in temperature quickly melts the ice that may have accumulated on the filter beds and the sewage sinks rapidly beneath the surface.

Experiments previously detailed show that between these temperatures nitrification is comparatively active.

There was no offensive odor at the beds, with the exception of that coming from a deposit of sludge near the gate chamber, and this did not extend for any great distance. I am informed that it is usual to keep this sludge spaded beneath the surface. The surface of the beds are occasionally turned over with a plow to assist in keeping them from becoming sodden so as to exclude the air.

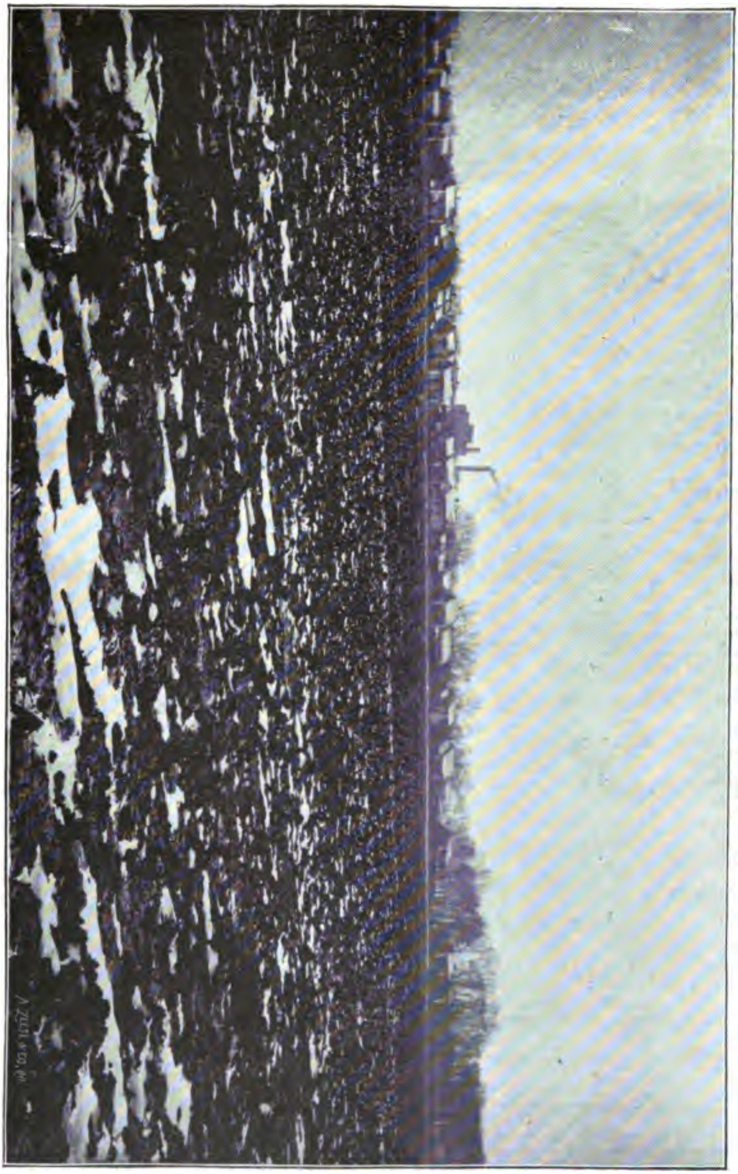
A sample of the crude sewage was taken at the end of the carrier for analysis and also a sample of the purified effluent was taken from the man-hole to which the tile drains converge. The effluent was clear and sparkling and not unpleasant to the taste. The table below contains the results of an analysis of the samples collected as above stated.

ANALYSIS OF CRUDE AND PURIFIED SEWAGE FROM THE PULLMAN SEWAGE FARM.
(PARTS PER 100,000.)

	Crude Sewage.	Purified Sewage.
Temperature	51° F.	38° F.
Albuminoid Ammonia	.60	.040
Free Ammonia	.30	.037
Nitrogen as Nitrates	.41	.180
Oxygen required to oxidize organic matter	6.40	.760
Chlorine	4.20	2.100

The degree to which the purification has proceeded (assuming that there has been no concentration or dilution of sewage

PLATE XX.



Broad Irrigation Area—Pullman.

from evaporation, subsoil water or other causes) is indicated by the following Table.

Albuminoid Ammonia	.93½ per cent.
Free Ammonia	.88 " "
Nitrates	.56 " "
Oxidizable organic matter	.88 " "
Chlorine	.50 " "
Total Nitrogen in the Effluent	.21½ " "

Much more favorable results may be expected, of course, during the warmer weather. The intention was to ascertain the conditions at about the most unfavorable season. As previously stated the soil is not adapted to purify large quantities of sewage having too much finely divided organic matter in its upper layers which interferes with aëration and also too retentive a subsoil.

Plate XX is reproduced from a photograph of the area devoted to broad irrigation and crops. Sewage is applied to this area whenever the weather in spring and fall is favorable and it can be applied without interfering with the crops. In general, however, no sewage is applied to growing crops. The sewage is distributed to this area through a system of vitrified pipes having hydrants at convenient intervals from which the sewage is allowed to flow over the surface of the ground. Sewage is also applied to meadow lands adjoining this area in the spring.

The principal crops raised upon the sewage farm are early potatoes, cabbages, beets, onions, celery, cauliflower, parsnips and squashes. Mr. Campbell, the superintendent, informs me that the gross receipts from the farm (140 acres) was about $12,000 last year.

The experiments of the Massachusetts State Board of Health and the results obtained at Pullman under conditions more than usually unfavorable indicate that the disposal and purification of sewage on the land in this climate is entirely practicable in a great majority of cases.